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# ORIGINAL ARTICLES.

## The Rocks of the Lupata Gorge and the North Side of the Lower Zambezi.

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THE alkaline volcanic rocks of the Lupata Gorge were described in 1915 by E. O. Teale and R. C. Wilson,[1] and in 1922 F. P. Mennell [2] showed that at the entrance to the gorge these rocks were preceded by a sheet of columnar rhyolite intercalated between two series of sediments, for which he proposed the name of the Upper and Lower Lupata Sandstones respectively; the Lower series rested on Karroo basalts, and these upon Karroo sandstones. In 1923, E. O. Teale and W. Campbell Smith [3] gave a detailed petrographical description of certain of the alkaline lavas and of the intrusive olivine-nephelinite (nepheline-basalt) of Sena Hill on the south side of the Zambezi.

Early in 1928, in consequence of permission kindly given by the Portuguese Administration, the writer [4] was able to make a reconnaissance of the country lying north of the Lower Zambezi.[5] In the course of this work it was possible to follow the rhyolite and the alkaline lavas of the Lupata Gorge northwards and eastwards until they died out, and to trace the Upper Lupata Sandstones along the north side of the Zambezi as far as Mutarara. Here the sandstones were found not only to rest upon a series of rhyolitic rocks comparable with those of Lupata, but also to be penetrated by two basaltic pipes similar to those of Sena Hill. Moreover, a more detailed examination of the Lupata Gorge sequence showed that the Upper Lupata Sandstones rest with strong unconformity upon the columnar rhyolite.

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[1] *Geogr. Journ.*, vol. xiv, 1915, p. 31, and also E. O. Teale, *Trans. Geol. Soc. S. Africa*, vol. xxvi, 1923, p. 103.

[2] Geol. Mag., Vol. LIX, 1922, p. 169.

[3] Geol. Mag., Vol. LX, 1923, pp. 226–37.

[4] The main part of the paper is written by Dr. F. Dixey: the petrography by W. C. S.

[5] F. Dixey, "Nyasaland Protectorate," *Annual Report of the Geological Survey Department for the year* 1928, pp. 7–8. A short account of the physiographical features of the Lupata Gorge has been given elsewhere. F. Dixey, *Geogr. Journ.*, vol. lxxii, 1928, pp. 454–5, 2 pls.

The Lupata rocks north of the Zambezi were laid down upon an uneven surface of basalts and sediments of Karroo age as well as rocks of the crystalline series. The main features of this ancient surface are still recognizable to-day. Such are the broad ridge of Karroo basalt that separated the Zambezi and the Shire areas of deposition of the Upper Lupata Sandstones and Muambe Hill, which was largely submerged by the Lupata rhyolitic rocks and associated sediments. Patches of these rocks still rest upon the flanks of Muambe, which consists of high ridges of hard grits enclosing crystalline limestone rich in iron ores.

The alkaline lavas of Lupata Gorge are overlaid, as described by Mennell, by coarse pebbly sandstones derived from the lavas themselves. My observations north of the Zambezi led me to believe that these later (post-Lupata) Sandstones were confined almost entirely to the area between the north-eastern limb of the main outcrop of the alkaline lavas and the Zambezi, but on the south side of the river, as I understand from Mr. F. P. Mennell, they are developed to a much greater extent.

## THE AGE OF THE LUPATA SERIES.

On the evidence of pebbles from the alkaline series included within fossiliferous beds considered to be of Upper Cretaceous age, Mennell regards the lavas as being at least of Lower Cretaceous age, whereas Teale and Campbell Smith[1] have called attention to their close resemblance to the "Kapitian phonolites" of Kenya Colony, which Professor J. W. Gregory[2] regards as of Upper Cretaceous age. The only additional fossil evidence now available (p. 251), namely that of the shaft of a limb-bone of a large Theropodous Dinosaur, as identified by Dr. S. H. Haughton, does no more than indicate the age of the lavas as lying between the two limits already mentioned.

Probably the most satisfactory indication as to the age of these rocks is to be obtained by comparing them with the other Mesozoic rocks of this part of Africa; such comparison suggests an early Cretaceous age, probably Neocomian and Aptian.

The nearest recorded terrestrial beds comparable with the Lupata Sandstones are the Dinosaur Beds of the northern end of Lake Nyasa,[3] to which they bear a very close resemblance both in lithological character and in their relations to the Karroo and to the Rift Valley. The Dinosaur Beds may be regarded as being largely equivalent to the Tendaguru Beds, in which case they would be of late Jurassic or early Cretaceous age, and would represent a terrestrial phase contemporaneous with the Tendaguru estuarine phase ; an alternative view is that they are slightly younger than the Tendaguru Beds, and, therefore, definitely of Cretaceous age (S. H. Haughton, *in litt.*). This latter view receives considerable support from the fact that the Lakonde Beds, which lithologically resemble the Dinosaur Beds and are of Aptian age, rest discordantly upon the Tendaguru Beds[1] and extend westwards from them to within 70 miles of the northern end of Lake Nyasa.

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[1] Loc. cit., p. 227.

[2] *The Rift Valleys and Geology of East Africa*, 1921, p. 105.

[3] F. Dixey, *Trans. Roy. Soc. S. Africa*, vol. xvi, pp. 55–6, and S. H. Haughton, ibid., vol. xvi, pp. 67–75.

When the terrestrial Makonde Beds are followed in the opposite direction towards the coast, they graduate into shallow-water marine sediments with Aptian fossils ; here they rest discordantly upon similar Neocomian sediments that pass locally into coarse conglomerates and calcareous sandstones[2] reminiscent of the Lupata Sandstones. Farther south, in Portuguese East Africa, terrestrial sediments comparable with the Makonde Beds make up the Mavia plateau of the Lower Ruvuma, and undergo a similar transition to marine facies when followed to the east.[3] These early Cretaceous sediments rest directly upon the crystalline rocks and extend southwards along the coast[4] almost to the latitude of the Lupata Sandstones ; they reappear at Lorenço Marques, where again they rest upon pre-Mesozoic rocks.

In view of these circumstances it is reasonable to regard the Lupata Sandstones as the terrestrial equivalent of these early Cretaceous marine sediments. Moreover, the discordance known within the early Cretaceous would appear to be represented at Lupata by the unconformity between the Lower and the Upper Sandstones ; for just as the Aptian transgresses across the Neocomian on to the pre-Mesozoic rocks, so the Upper Lupata Sandstones step across the Lower on to the Karroo and the pre-Karroo formations.

## THE LUPATA SUCCESSION.

As already indicated the volcanic rocks of the Lupata Gorge comprise a lower rhyolitic series and an upper alkaline series. Each group includes at the base variable pebbly sandstones, and the alkaline series is overlaid by a third group of pebbly sandstones. Although there is no obvious unconformability at the upper end of the gorge, examination of the country lying immediately to the north shows that there is a stratigraphical break of considerable magnitude between the rhyolitic series and the alkaline series. The Upper Lupata Sandstones of Mennell rest upon a deeply-eroded surface of the columnar rhyolite, so that 2½ miles north of the gorge they overstep completely on to the Lower Sandstones, and still farther north on to the Karroo lavas and older rocks. Moreover, south of the gorge the scarp of the rhyolitic series continues to the south-west, whereas that of the alkaline series runs for some miles in a southerly direction. In the present account it is proposed therefore to include the Lower Lupata Sandstones with the rhyolitic series, and the Upper Lupata Sandstones with the alkaline series.

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[1] E. Krenkel, *Geologie Afrikas*, part i, 1925, p. 310.

[2] F. R. C. Reed, *Geology of the British Empire*, 1921, p. 74.

[3] *Handbook of Portuguese Nyasaland*, I.D., 1161, Naval Intelligence Division, London, p. 33.

[4] A. Holmes, *Quart. Journ. Geol. Soc.*, vol. lxxiv, 1917, p. 31.

Additional evidence for the unconformity is given by the mapping of the area. As will be seen in a later paragraph the rhyolitic series wraps around the base of the Muambe mass and ascends its flanks to a height of not less than 1,000 feet. Nevertheless, previous to the deposition of the sediments at the base of the alkaline series, the erosion of the rhyolitic series was such that the later beds were laid down partly upon the rhyolites and partly upon the Karroo and older rocks. Moreover, while the outcrops of the rhyolitic series, including those of the Sinjal–Mutarara ridge, are widely scattered, that of the alkaline lavas is compact and relatively small.

### (1) *The Rhyolitic Series.*

The rhyolitic series outcrops in three separate areas, namely at the upper end of the Lupata Gorge, at Muambe, and north of Mutarara. The first two outcrops are separated only by a temporary overstep of the alkaline series on to the Karroo, but the third outcrop lies about 95 miles south-east of the other two. It will be convenient in the following paragraphs to describe these three outcrops separately.

Mention should be made at this point of yet another group of rhyolites that outcrops between the Lupata rhyolites and those of Mutarara. These rhyolites, although resembling in some respects certain of the rhyolites at the entrance to Lupata Gorge, are none the less considered to be of Karroo age for the following reasons. Their outcrop is continuous and parallel with the north bank of the Zambezi for about 30 miles. They rest throughout in apparent conformity upon Karroo basalt and are succeeded directly by a considerable thickness of the basalt. In this respect and in petrographical characters they resemble the Lebombo rhyolites lying near the Anglo-Portuguese border west of Lorenço Marques. Moreover they differ from the Lupata rhyolites outcropping to the north and the south of them both in uniformity of character and in the absence of associated sediments and well-developed pyroclastic rocks.

(*a*) *Lupata Gorge.*—The rhyolitic series at the entrance to Lupata Gorge comprises essentially the great flow of columnar rhyolite and the underlying pebbly sandstone; pyroclastic rocks have not been observed in this area; but locally the eroded surface of the rhyolite is overlaid by a few feet of breccia [N 731] consisting of angular fragments of rhyolite in a compact red matrix.

The pebbly sandstones rest upon an eroded surface of Karroo basalt and attain a maximum observed thickness of 350 feet, although the total thickness is probably rather more than this. They vary considerably in texture and degree of assortment, and are usually stained pink or red. Like the Upper and the post-Lupata Sandstones they are characterized by the number and great size of the included well-rounded boulders of gneissose rocks ; here the boulders range up to 2½ feet in length, and they are accompanied by representatives of the Karroo basalt and sandstones.

The rhyolite is best exposed at the entrance to the gorge,[1] where it attains a thickness of 260 feet and forms a high colonnaded cliff capping the scarp of the pebbly sandstones.

The hand-specimens of the rhyolites of the main scarp at the end of the traverse from Garufa to Sungo [N 732] and at the upper end of the Lupata Gorge [N 734] are various shades of purple-drab, aphanitic, generally compact, and showing good flow-structures which often weather out strongly on the surface. Some specimens have the appearance of having consolidated from a pasty consistency, rounded pellets of purple-drab rhyolite being faintly outlined in a slightly darker matrix. The pellets sometimes weather out, producing a pseudo-vesicular surface. In thin sections there is little to be made out, the rocks being "felsitic", crypto-crystalline, permeated by poeciltic patches of quartz (?) which may be a secondary re-crystallization. Irregular patches of iron oxides may represent altered amphibole. Biotite, probably secondary, occurs as minute flakes here and there.

A chemical analysis of the freshest available specimen [N 732b] from the Sungo end of the Garufa-Sungo traverse was made by Mr. M. H. Hey, of the Mineral Department, British Museum, whose results are given below. The rock is extremely fine-grained and compact and quite devoid of phenocrysts. Its density was determined as 2·46.

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|---|---|
| $SiO_2$ | 74·35 |
| $Al_2O_3$ | 11·99 |
| $Fe_2O_3$ | 2·27 |
| FeO | 0·32 |
| MgO | 0·03 |
| CaO | 1·16 |
| $Na_2O$ | 1·97 |
| $K_2O$ | 4·86 |
| $H_2O$ + 110° | 1·44 |
| $H_2O$ — 110° | 1·06 |
| $TiO_2$ | 0·06 |
| $P_2O_5$ | 0·034 |
| $ZrO_2$ | 0·005 |
| S | 0·12 |
| Cl | tr. |
| $CO_2$ + C | 0·05* |
| (Co, Ni)O | tr. |
| MnO | 0·004 |
| Less equivalent of S | 0·05 |
| | 99·72 |

* Difference between total water and loss on ignition.

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[1] See *Geogr. Journ.*, vol. lxxii, 1928, pl., p. 453.

The composition is that of a normal rhyolite (liparite) with rather high $Fe_2O_3$ for a rhyolite, and very definite predominance of $K_2O$ over $Na_2O$. It resembles the analysis made by Professor Reinisch of the rhyolite of the Lebombo district described by J. McC. Henderson, but the possibility of the Lupata rhyolites belonging to the rhyolites at the top of the Karroo has been considered (by Dr. Dixey) and rejected on field evidence. The Lupata rhyolites do not contain the phenocrysts of felspar and augite which are abundant in the Lembobo rhyolites described by Henderson[1] and Prior.[2] Otherwise the rhyolites of the two localities show the close family resemblance which all rhyolites present.

Prior to the deposition of the alkaline series the rhyolite suffered extensive erosion and some gentle folding. The main sheet of rhyolite was deeply dissected and in some cases, as in the gap in the rhyolite scarp on the Sungo-Garufa path 2½ miles north of Lupata Gorge, the erosion was carried deep enough to reach the underlying sandstones; moreover a mile farther north the alkaline series was laid down directly on the Karroo basalt. Excellent sections showing the relations between the rhyolite and the Upper Lupata Sandstones may be seen along the lower course of the Makale Stream, a small left tributary of the Rurera, where it cuts a series of deep gorges across the rhyolite scarp. The sections clearly demonstrate how the deep steep-sided valleys carved into the rhyolite were completely submerged during the succeeding sedimentary phase.

(*b*) *Muambe.*—The rhyolitic series of this area occupies the tract between the scarp of the alkaline series and the southern foot of Muambe; scattered outcrops lie also around the flanks of Muambe. The main outcrop comprises a series of wooded scarps and dip-slopes that frequently attain a height of several hundred feet. It is evident that in pre-rhyolite times, as now, Muambe and the neighbouring hills formed isolated upstanding masses which became partially submerged, to a depth of fully 1,000 feet, by the accumulations of this period. Although gentle folding took place before the deposition of the alkaline series, the older group is for the most part inclined towards the younger; moreover, the erosion at that time was such that on either side of the Muambe area the alkaline series was finally laid down upon Karroo and older rocks.

As may be expected, the thickness of the series varies considerably from place to place, but probably the original maximum exceeded 1,000 feet. The beds comprise mainly sandstones, with intercalations of rhyolite and of pyroclastic rocks; the first-formed deposits were sandstones, but the volcanic rocks increased in importance towards the top, so that around the flanks of Muambe the series is represented at the higher levels principally by patches of rhyolite and of tuff.

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[1] J. McC. Henderson, *Trans. Geol. Soc. S. Africa*, vol. xii, 1909, p. 29.

[2] G. T. Prior, *Annals Natal Museum*, vol. ii, 1910, p. 152–6.

The lithic tuffs of this series are brilliant ochre-red to brick-red, crowded with fragments of pale-buff rhyolite and very small chips of felspar. They vary considerably in the degree of coarseness and in admixture with sedimentary material. The fragments in the tuff [N 676] from the south-west corner of Muambe are usually less than ½ cm. across, though occasionally they reach as much as 2 cm. Another specimen from the same place [N 756b] contains lapilli of vesicular rhyolite up to 4 cm. across. Other tuffs [N 666 and N 761] from the north-east corner and from the west flank of Muambe are similar but more friable, with lapilli of rhyolite stained pink from the bright-red matrix. The rhyolites are variable in colour, white, buff, pink, or mauve ; they are usually of fine compact texture, but sometimes they consist of highly vesicular blocks embedded in a white flinty base.

A rhyolite [N 668] from the north-east corner of Muambe Hill is a streaky pinkish lithoidal rhyolite containing very small but fairly numerous fragments of felspar. Under the microscope the felspars show well-developed cross-hatching like microcline, but others show very thin multiple twin-lamellae and a refractive index less than Canada-balsam, so that it seems likely that these felspars are anorthoclase. It is as well, however, to bear in mind that these felspars are fragmental and may include microcline and other felspars derived from the crystalline schists or other underlying rocks. The groundmass is cryptocrystalline, full of opaque alteration products.

Whereas the tuffs sometimes attain to a thickness of one or two hundred feet, the rhyolites are rarely more than a score or two of feet in thickness. In this respect, as well as in the greater proportion of pyroclastic rocks and the less coarse texture of the sediments, the development of the series in this area differs from that of Lupata Gorge.

What appear to be scattered outcrops of the rhyolites lie also around the flanks of Chuara Hill several miles north of Muambe, and the specimens [N 767) compare fairly well with the rhyolites of Muambe Hill described above. Chuara Hill itself appears to consist of soda-rich intrusive rocks [N 766, 757] and is regarded as probably pre-Karroo.

(*c*) *Mutarara Area.*—Northwards from Mutarara there extends a broad ridge of pebbly sandstones and rhyolitic rocks that lies between the Zambezi and the crystalline rocks of the Port Herald Hills ; the ridge rises from beneath the river alluvium at Mutarara and steadily increases in height until at a distance of half-a-dozen miles to the north it stands about 1,000 feet above the river. Here the ridge consists of two thick sheets of volcanic rocks and associated sediments dipping successively towards the river, where they pass beneath an upper series of pebbly sandstones that contain large pebbles of the rhyolitic rocks at their base. The earlier beds were laid down upon an uneven floor of Karroo basalts and crystalline rocks, so that as the lower sandstones filled up the deeper hollows the volcanic rocks overlapped on to the flanks of the basalt hills. This succession evidently represents the Lupata Sandstones and the rhyolites of Lupata Gorge.

The sandstones are usually coarse and felspathic, and slightly calcareous, and they are variably reddish-brown, pink, mauve, and purplish in colour; the larger included pebbles consist mainly of gneisses, with some quartzites and rhyolites, but the smaller pebbles consist chiefly of basalt and of vein-quartz. Bedding, lamination, and current-bedding are variably developed within these beds. Near Baue Station the lower sandstones attain a thickness of fully 400 feet.

The volcanic rocks consist principally of red and mauve rhyolites, ashes, and coarse volcanic débris. They attain a maximum thickness of about 900 feet at the higher part of the ridge. They die out in both directions, for at Mutarara they appear only as a few thin beds, and to the north at Sinjal, they are wholly absent. This variation would appear to be due, as at Lupata Gorge, partly to irregularity of deposition and partly to erosion preceding the accumulation of the upper sandstones.

The following notes may serve to describe the characters of the specimens collected in this region:—

One mile east of Old Mutarara, interstratified with the sandstone is a lithic tuff [N 620] which consists of angular fragments of purple rhyolite in a brick-red matrix. The rhyolite is extremely fine-grained and resembles those described above from Lupata Gorge. The matrix is tufaceous and contains a few angular fragments of quartz similar to those which are so abundant in the tufaceous sandstones of the Muambe Hill district.

The other tuffs of this locality, 1½ miles east of Old Mutarara [N 622], have a very hard compact ochre-red matrix crowded with fragments of purple "rhyolite" and a paler light drab "felsite" and rhyolite. The crystallization in some of the rhyolites has allowed the development of long thin fibres of felspar, arranged in closely packed parallel groups. Some altered ferromagnesian minerals occur but were not identified.

On the ridge 6 miles north of Mutarara the upper volcanic horizon in the rhyolitic series has yielded hand-specimens of a streaky rhyolite [N 634], Indian red to pinkish vinaceous in colour, and full of included fragments mostly small in size. The lower horizon is represented only by a pale ochre-red tuff [N 636] crowded with fragments of rhyolitic rocks, and the intervening layer [N 635] in very similar but perhaps more definitely fragmental and tufaceous. This resembles the ochre-red tuffs of Muambe Hill and like these carries, in addition to the abundant rock-fragments, numerous fragments of felspar crystals. Some inclusions of a purple-drab aphanitic rock up to 10 cm. across found in these tuffs [N 635] are probably quartz-trachyte or solvsbergite. A section of one of them shows numerous very small phenocrysts and microphenocrysts of felspar in a groundmass of a cryptocrystalline aggregate of felspar and quartz strewn with minute shreds and patches of an opaque alteration product of some ferromagnesian mineral. There are a few microphenocrysts of the same material in the form of long prisms or blades. The habit of the felspars is tabular, parallel to (010). They form simple Carlsbad-twins and give extinction angles up to 10° on (010). On sections nearly normal to (010), extinction angles up to 3° were measured from the trace of the Carlsbad twin-plane. It is possible, then, that these phenocrysts are anorthoclase. The form of the opaque pseudomorphs of the ferromagnesian mineral quite suggests riebeckite.

### (ii) *The Alkaline Series.*

The alkaline series comprises principally a lower group of pebbly sandstones followed by sandy tuffs (Upper Lupata Sandstone) and an upper group of alkaline lavas and tuffs, with a few interbedded sediments.

The series attains its maximum development of probably several thousand feet in the Lupata area, to which the volcanic rocks are very largely confined.

(*a*) *Earlier Sediments and Tuffs.*—The pebbly sandstones and the pyroclastic rocks beneath the lavas show great variations in character and thickness from place to place; moreover, either one may be developed to the complete exclusion of the other. The sediments are dominantly red and white pebbly sandstones, but pink, mauve, and purple tints appear locally; they are sometimes felspathic or calcareous, and they vary from fine red marly sandstones to grits with pebbles and boulders ranging up to 2½ feet in length; the smaller pebbles consist mainly of quartz, but the larger ones include Karroo rocks and various gneisses. The sandstones may be massive, current-bedded, flaggy or laminated. The pyroclastic rocks include fine red tuffs, red sandy tuffs, greyish pulverulent tuffs, pale-grey porcellanous tuffs, and also hard red and purplish tuffs and agglomerates. The tuffs immediately underlying the earliest flow are of rhyolitic character.

At Lupata Gorge the sandstones are about 300 feet thick, and the pyroclastic rocks, comprising mainly red tufaceous sandstones with a few pebble beds, about 150 feet. Three miles to the north the pebbly sandstones are 80 feet thick, and they are overlaid by 100 feet of the tufaceous beds. On the north crop, west of the Minjobva gap and along the Pemba stream, the total thickness of the two groups is many hundreds of feet, but several miles to the east the pebbly sandstones are again cut out.

Traced eastwards from Muambe to Chiganga these beds overstep from the rhyolitic series on to the Karroo. Here they are again of variable character. The pebbly sandstones, containing large boulders of gneiss and of Karroo grits, pass upwards by alternation into a series of greyish tuffs, red sandy tuffs, and red and white banded ashes. These beds are well exposed near and in the bed of the Sorodzi, which here runs for several miles along the foot of the Domue-Sarula scarp. At Chiganga the red tuffs exceed 200 feet in thickness, but several miles farther east, where the Sarula flow dies out, these beds are entirely absent, and the lava rests directly upon hard purplish grit.

Beyond the south-eastern extremity of the outcrop of the alkaline lavas the sediments can be followed continuously to Sinjal, where they step across from Karroo on to crystalline schists, back again on to Karroo basalts, and finally on to the rhyolitic series of the high ridge running northwards from Mutarara.

At Sinjal the beds consist of variable red sandstones dipping about 10° west-north-west and nearly 500 feet thick. Certain of the beds appear to be ashy, and there are many intercalations of coarse pink and white pebbly grits with boulders of gneiss and of Karroo rocks up to 2 feet in length. Pebbly sandstones overlying Karroo lavas were recorded at Sinjal by A. R. Andrew and T. E. G. Bailey,[1] but were not differentiated by them from the Karroo series.

At Mutarara they form the western side of the high ridge and pass beneath the river to reappear on the Sena side, forming the low plain, which rises about 50 feet above the river, and the flanks of the Sena Hills. The dip is about 6° to the south-west. Between Mutarara and Sena Hill the sediments comprise a thickness of about 1,250 feet.

The Mutarara sandstones, as well as the Sena sandstones, which are obviously to be included with the upper part of the Mutarara beds, are regarded as being older, and not younger, than the Lupata alkaline lavas.

On both sides of the river the upper sandstones are penetrated by small pipe-like intrusions of a dark basaltic rock which in the case of Sena Hill has been described by Teale and Smith [2] as olivine-nephelinite, presumed to be of Tertiary age from the close similarity with a post-Eocene intrusion in the Inkweyri Hills in the Sheringoma plateau. On the west bank there are eleven or more such intrusions, and on the east two have recently been observed, one half a mile east of the proposed bridge site,[3] and the other 2 miles to the north on the bank of the river.[4] The intrusions give rise to scattered conical hills, but although the cones range from 100 to 400 feet in height the basaltic cores are relatively very small, since they usually range only from 25 to 30 yards in diameter. Sena Hill consists of two intersecting cones with at least four intrusions.

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[1] *Quart. Journ. Geol. Soc.*, vol. lxvi, 1910, pp. 189–237.

[2] Loc. cit., p. 228.

[3] F. Dixey, *Nyasaland Protectorate Geol. Surv. Report for* 1928, 1929, p. 8.

[4] The specimen [N 619] from 2 miles north of the proposed bridge site is a limburgite. The hand-specimen is compact, blackish-slate in colour, and shows a few small phenocrysts of olivine (1–2 mm.) in an aphanitic groundmass. Under the microscope it is seen to consist of very small phenocrysts and microphenocrysts of colourless olivine in a mass of very slender microliths of pale buff (tilleul-buff) augite and a small amount of dark isotropic interstitial

The Upper Lupata sandstones are represented also in the Lower Shire Valley under conditions analogous with those of the north bank of the Zambezi. On both sides of the broad ridge comprising the Lower Shire-Zambezi watershed they dip gently away from the Karroo basalts and sediments and pass gradually beneath the river alluvium. The Lower Shire sediments attain an exposed thickness of several hundred feet, and are particularly well exposed in the Tere area and along the middle course of the Pwadzi River. In a small outlier of red sandy marl resting on basalt about 3 miles west-south-west of Chirunda Hill, on the Anglo-Portuguese border, these sediments have yielded the shaft of a limb-bone of a fossil reptile which, in the opinion of Dr. S. H. Haughton, was probably a large Theropodous Dinosaur (see p. 242).

(*b*) *The Alkaline Lavas and Associated Tuffs and Sediments.*—The lavas are best exposed in the vicinity of Lupata Gorge, which cuts across them for 9 or 10 miles. The earlier flows appear to have extended farther to the south-east than the later flows, and both on the north and on the south side of the Zambezi (as I am informed by Mr. F. P. Mennell) the volcanic rocks die out in this direction. They thus form a broad crescent-shaped outcrop, which appears to be due to the subsequent development of a north-west to south-east synclinal trough, down which the Zambezi ultimately flowed. In general the flows attain their highest altitude around the outer or convex margin of the crescent, where their worn edges give rise to a bold continuous scarp that runs from the upper end of the gorge through Domue and Linyanga crests to the point where the lavas finally die out, a total distance of about 60 miles. At Domue, for example, the scarp, of which the upper 700 feet consists of lava flows, reaches a height of nearly 1,100 feet, and similarly near the upper end of the gorge the highest crests stand fully 1,000 feet above the river. The larger flows attain to thicknesses of 100 to 250 feet, and along the higher scarp they can frequently be seen to overlap one above the other.

The form of the uplands due to the outcrop of the lavas is determined mainly by the inward dip of the larger and more resistant flows, but in the neighbourhood of the Zambezi the country is much

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material. The last consists of colourless glass crowded with extremely minute opaque cubes and grains (0·006 mm.), chiefly magnetite, but containing also some rhönite. The section contains occasional xenocrysts of quartz surrounded by a zone of greenish augite and (?) felspar. This rock is a limburgite "of the second kind", described by H. Bücking. It is closely akin to the olivine-nephelinite (nepheline-basalt) of the hills near Sena, previously described. Other parts of the intrusion might be expected to show the holocrystalline-porphyritic development like that described from Baramwana Hill.

dissected by tributary streams, and elsewhere on the highlands a few peaks, marking the remnants of later flows, stand well above the general level. From any one of these peaks the vegetation can be seen to reflect the structure of the area, for in general the backs of the flows form grassy uplands, whereas their edges appear either as rocky cliffs or as wooded scarps. Ncheni peak, near the eastern margin of the outcrop, appears to represent the flank of a vent of relatively late age.

The uplands as a whole are very dry for a large part of the year, and the scarcity of water is a serious factor in the examination of the area.

Fresh specimens of the lavas and associated rocks can usually be obtained near the scarps, but over the greater part of the outcrop the surface rocks have weathered down to pale-buff or yellowish masses of uniform appearance.

### (*c*) *Petrography of the Alkaline Lavas.*

#### PHONOLITES.

The phonolites are almost all of kinds similar to those described in 1903 by G. T. Prior[1] from the specimens collected by J. W. Gregory in Kenya Colony in 1892–3. These rocks, together with some of those collected by Gregory in 1919, and described by Miss A. T. Neilson,[2] have been the subject of careful study by one of the authors (W. C. S.) based on chemical analyses made with the aid of a grant from the Royal Society. The experience gained in the course of this work has proved of great value in the study of other alkaline volcanics, and in particular of those now being briefly described.

The main flow on the Domue ridge is a phonolite almost free of phenocrysts, characterized by an aphanitic groundmass which has the composition and texture described by Prior in his "Kamasia type" from the Kamasia or Tukin Hills, west of Lake Baringo.

These rocks vary in colour from dull greenish-black to chocolate; some of them are mottled. They are compact, aphanitic, with smooth fracture and slightly resinous lustre. Some of them contain small tabular crystals of orthoclase (or soda-orthoclase) and very small nephelines. A few contain microphenocrysts of a pea-green pyroxene.

The groundmass in the best crystallized example [N 447] shows patches of cossyrite, aegirine, or aegirine-augite, and of the same sky-blue riebeckite-like amphibole described and figured by Prior.[3] The cossyrite forms rounded spongy or moss-like patches, but the soda-pyroxenes show a marked tendency to develop prismatic outlines. Very minute felspars and nephelines occur throughout all the other constituents. In some specimens [N 660] a colourless isotropic base can be distinguished, which seems to consist, at any rate in part, of sodalite.

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[1] *Min. Mag.*, vol. xiii, 1903, pp. 237–41.

[2] In J. W. Gregory, *The Rift Valleys and Geology of East Africa*, London, 1921, pp. 388–407.

[3] Loc. cit., p. 238, and fig. 4, pl. v.

These types are found along the Domue-Sarula ridge at a point 6 miles north-west of Chiganga [N 446–8], at Liyanga Hill [N 660] 3 miles north-west of Chiganga [N 431], and from the top of the Sarula scarp [N 416, 417]. Rather similar rocks, phonolites (Kenya type), but richer in nepheline, were recorded in 1923 from Chinje and Yajenje Hills on the south side of the Zambezi.[1]

A porphyritic phonolite forms a flow in the Boku scarp above the Sarula flow [N 459], and a similar rock was found on the traverse from Nkomadzi to Garufa [N 720, 721]. These vary in colour, like those described above, from dull greenish-black to clove-brown or chocolate. Phenocrysts, which are rather abundant, are of felspar (? soda-orthoclase) and nepheline, and there are microphenocrysts of a pea-green pyroxene associated with magnetite. The groundmass differs from the others in the better individualization of the aegirine-augite, which forms rounded grains 0·006 mm. in diameter, and is the dominant dark mineral. The rest of the groundmass consists of flakes of cossyrite and abundant laths of felspar in a turbid groundmass which when fresh is seen to contain very minute nephelines and colourless isotropic material. Some patches rich in magnetite-dust [N 721] may represent a resorbed amphibole. Katophorite seems to be very rare in these rocks. The difference in composition between these and the Kamasia type is probably very slight, and they probably come very near to Prior's phonolite (Kenya type).[2] N 720, a flow-banded lava, is only a devitrified glassy form of N 721.

On the continuation of the west-to-east traverse from Garufa to Sungo, separated from the phonolites just described by red tufaceous sandstone [N 722], is a compact aphanitic phonolite, deep slate-olive to iron-grey in colour [N 723] and very similar in composition to those described above. This consists of laths of orthoclase, with aegirine-augite and cossyrite in minute patches in a colourless rather altered groundmass which is isotropic but contains some altered nephelines and also small crystals (0·1 mm.) which look like altered icositetrahedra of analcite. This phonolite immediately overlies a very remarkable "blairmorite" described below, which is the lowest lava in this section of the alkaline series.

A dark neutral-grey porphyritic (dopatic) phonolite from the upper part of Ncheni Hill [N 657] has a groundmass showing the same constituents as those described above, but richer in felspar and showing well-developed trachytic texture. It is not like any particular type known from Kenya Colony, but its close relationship to the Kenya type is obvious. The phenocrysts are nepheline and soda-sanidine, with small phenocrysts of aegirine-augite. The groundmass consists of extremely thin long laths of turbid felspar between which are wedged minute (0·02–0·03 mm.) prisms of nepheline, and small patches (0·15 mm. across) of sodalite or analcite sometimes showing hexagonal outlines. The coloured minerals present are cossyrite in "mossy" patches and aegirine-augite fringed with aegirine. Katophorite is scarce. The cossyrite is the dominant ferromagnesian mineral. It is sometimes pleochroic: X′ tawny-olive, Y madder brown.

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[1] E. O. Teale and W. Campbell Smith, Geol. Mag., Vol. LX, 1923, p. 230.
[2] Loc. cit., p. 239.

The Sarula flow, several miles south-east of Chiganga, near the south-east end of the lava outcrop is represented by dusky olive-green aphanitic rocks [N 486, 487], with a mesh of felspar laths in a glassy base, containing microliths or crystallites of aegirine-augite, cossyrite, and magnetite. These may be partly glassy equivalents of phonolites (Kenya type). They are separated by a bed of tuff from the overlying Boku flow.

## KENYTES.

Other porphyritic phonolites belong to those rocks which have been variously described as kenytes and Kapitian phonolites.[1] Rocks identified as "olivine-free types of Kapitian phonolite" have already been described from the Lupata Gorge.[2] Further examples of these rocks are now recorded from near Penze on the track to Chirisa [N 687, 690].

These are porphyritic (perpatic to dopatic) with phenocrysts of felspar, nepheline, and rarely of pyroxene in a dark neutral-grey aphanitic groundmass. The felspar phenocrysts are probably soda-orthoclase, they are tabular parallel to (010) and seem to be bounded by the forms *m*, *c*, and *x*. Nepheline, cinnamon-drab to army-brown in colour, occurs in short prisms ½ cm. across. The pyroxene, which occurs rarely as small phenocrysts, more commonly as microphenocrysts is an aegirine-augite with rather weak pleochroism from tea-green to light grape-green. Magnetite occurs as microphenocrysts.

The groundmass, extremely fine-grained and slightly altered, is the kind described by Prior in his phonolites (Kenya type): that is, patches of cossyrite, aegirine-augite and aegirine, and katophorite in irregular forms, often partly enclosing the minute felspar-laths and nephelines of the groundmass. The nephelines, more or less altered, are often surrounded by a fringe of aegirine or amphibole. The proportion of aegirine-augite to cossyrite is rather variable in different specimens. A careful study of the kenytes of Mount

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[1] I shall be able to show in another paper that many of the kenytes of Mount Kenya contain porphyritic nepheline as well as anorthoclase and are inseparable petrographically from the Kapitian phonolites: the name kenyte has been retained to cover both.

[2] E. O. Teale and W. C. Smith, loc. cit., p. 227.

Kenya has shown that they had originally this same kind of groundmass, which had been considerably altered in the original specimens described by Gregory.

Another kenyte occurred as loose masses near the foot of the scarp of Domue ridge about 6 miles north-west of Chiganga [N 445]. This is crowded with phenocrysts of felspar and nepheline in a chocolate-coloured groundmass. The interest of the specimen lies in the fact that the groundmass has crystallized in just the same way as the aphyric phonolites described above. The patches of cossyrite and aegirine-augite are well developed, but the rock is somewhat altered and none of the sky-blue amphibole or katophorite are identifiable. Microphenocrysts of pea-green pyroxene and associated magnetite are fairly frequent.

Closely allied to the kenytes just described, and linking them with the " blairmorites " described below, are some other porphyritic (dopatic) rocks, with phenocrysts of felspar and nepheline in great abundance but differing as regards the character of the exceedingly fine-grained groundmass and in the presence of analcite or its pseudomorphs as small phenocrysts. It seems impossible to separate them from the kenytes and they may provisionally be referred to as analcite-bearing kenytes.

The phenocrysts are of untwinned felspar with rather rounded edges, nepheline, analcite, rarely a nearly colourless augite, and very small crystals of ilmenite or magnetite (0·5–0·6 mm.). The " iron ores " are closely associated with apatite, and sometimes fringed with biotite. Minute cubes of pyrite occur in one specimen. The analcite appears in hand-specimens as very conspicuous crystals of a Prussian-red colour, often with a narrow white border. They are sometimes $\frac{3}{4}$ cm. across but for the most part are quite small (0·8 mm.), and in some specimens rather rare. They consist of a core of analcite surrounded by, or sometimes wholly replaced by, a fibrous mineral, presumably a zeolite. In some sections the replacing materials appear to be felspar and analcite, or felspar and the fibrous mineral.

The groundmass consists of minute laths of orthoclase, flakes of brown biotite, and grains of magnetite with cossyrite and aegirine-augite in a colourless isotropic base. The soda-amphibole and cossyrite are not always identifiable, but the minute flakes of biotite, pleochroic from yellow to chestnut, seem to be a constant constituent.

One of these analcite-bearing kenytes [N 688] occurs on the track from Penze to Chirisa between two of the kenytes described above, and like them is slightly vesicular. The felspar phenocrysts, which are rather square in cross section, may reach $1\frac{1}{2}$ cm. in length, and show up well with the fawn-coloured nephelines against the dusky green-grey groundmass.

Another analcite-bearing kenyte with fewer phenocrysts of felspar and a better crystallized groundmass [N 728] is from fallen blocks, representing the earliest alkaline lavas, on the road from Garufa to Sungo. The superficial likeness of these rocks to the "rhomb-porphyries" is well seen on the water-worn surface of the specimen.

From near Chirisa come two very striking specimens of these rocks [N 703, 705], with Prussian-red analcites, clove-brown nephelines, and abundant pale-grey felspars in a dark purplish-grey groundmass. Small phenocrysts of magnetite and of the nearly colourless pyroxene and minute cubes of pyrite are frequent. But for the presence of the analcites the fresher of these two specimens [N 705] is very similar to the kenyte from the core of Mount Kenya described by Gregory [1] and analysed by Prior.[2]

The analcite in these rocks might easily be mistaken in thin section for leucite, while some would regard it as necessarily secondary and, from its shape, pseudomorphous after leucite. H. S. Washington [3] and others have, however, shown clearly that in many rocks analcite is primary.

The discovery of these analcite-bearing kenytes lends support to the view expressed by Lacroix [4] that the "leucite" of the leucite-rhomb-porphyries, described by L. Finckh,[5] from Kilimanjaro are really analcite.

## BLAIRMORITE.

With the kenytes the close resemblance with the volcanic rocks of Kenya Colony ceases, and we are left with a series of rather altered lavas difficult to name and some remarkable lavas, blairmorites, with analcite phenocrysts reaching as much as 2 cm. in diameter, which have been very naturally mistaken in the field for leucite. The "leucite-bearing" lavas were recognized at two horizons by both F. P. Mennell on the south side of the Zambezi, and by Dr. Dixey on the north. The latter found them near Nkomadzi estate [N 715, 717, 718] on the track from Bandar to Garufa and near the base of the series on the path from Garufa to Sungo [N 724], where they are associated with brick-red sandy tuffs and a compact deep slate-olive phonolite described above.

The analcite in N 724 forms icositetrahedra up to 1½ cm. across, and on fresh surfaces has a resinous lustre and hazel or russet colour. It appears quite isotropic and pale-yellow in thin section, and shows traces of the twin-lamellae often seen in leucite, but determination of its density (2·2–2·3), refractive index (about 1·48), and chemical constituents proves it to consist wholly of analcite.

The rock also contains small phenocrysts of nepheline. The groundmass consists of abundant plates of clear orthoclase, with interstitial turbid patches containing some yellowish glass and both

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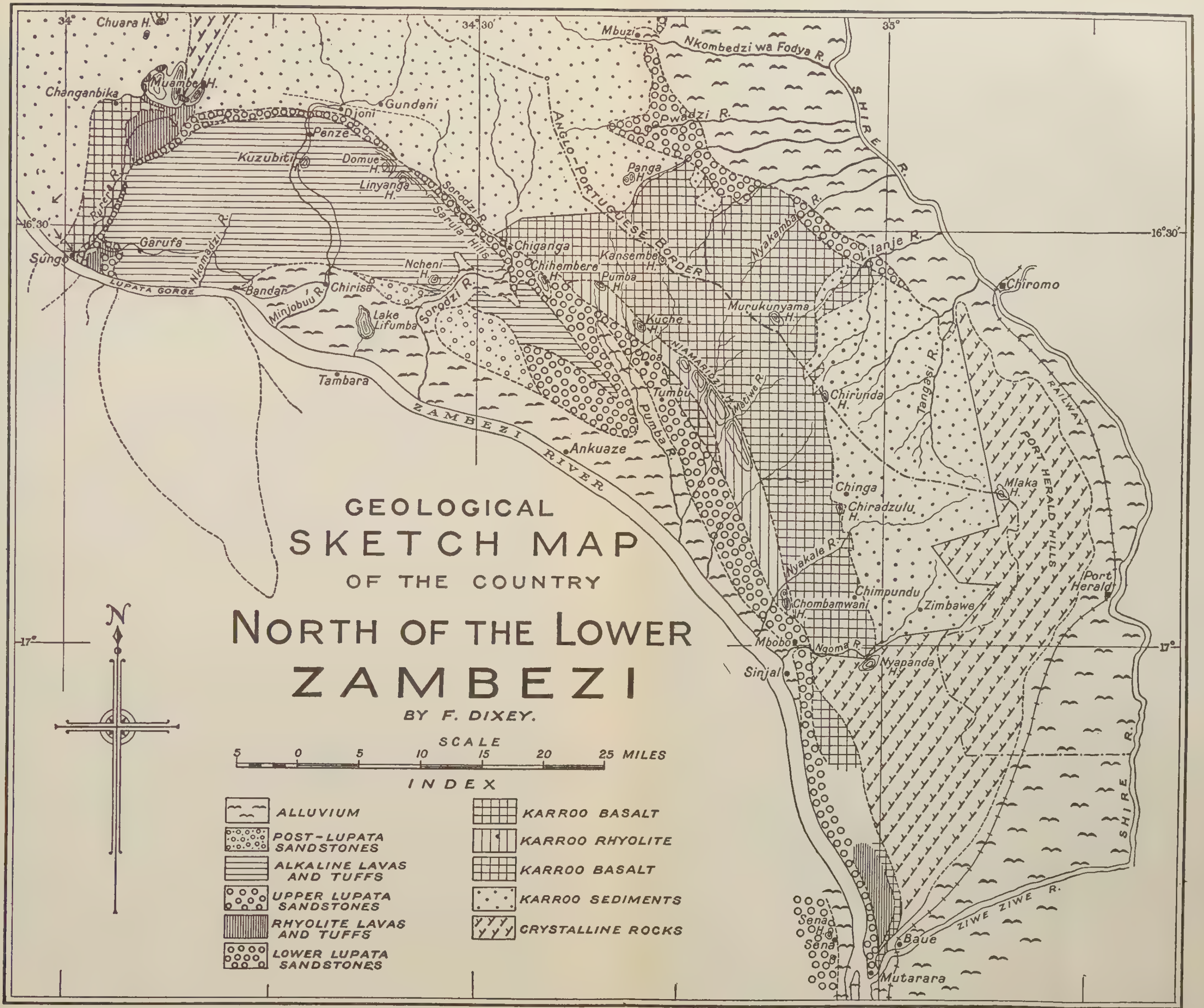
[1] *Quart. Journ. Geol. Soc.*, vol. lvi, 1900, p. 209.

[2] Loc. cit., p. 247.

[3] H. S. Washington, *Journal of Geology*, vol. xxii, 1914, p. 749.

[4] A. Lacroix, *Minéralogie de Madagascar*, vol. iii, 1923, p. 261.

[5] L. Finckh, *Rosenbusch Festchrift*, Stuttgart, 1906, p. 382.



In the map Minjobuu should read Minjobva, and Pumba R. should read Pemba R.

[*To face p.* 256.

felspar and interstitial patches full of included magnetite, some aegirine, doubtful cossyrite, and minute altered nephelines. At the edges of the analcite phenocrysts there is a turbid zone, possibly some kind of reaction rim. Rather frequent vesicles seem to indicate that the rock is clearly a lava.

The other examples of these remarkable rocks are so much decomposed that it is difficult to add any further remarks. In one the analcite is partly decomposed and in another [N 717] it is completely altered to a clay sometimes associated with a weakly birefringent fibrous mineral. These wholly altered phenocrysts vary in colour from white to vinaceous-lilac and vinaceous-brown. They weather out of the rock very readily.

Although the groundmass of these rocks is very indefinite there seems no doubt that they are to be referred to the " blairmorites " described from the Crowsnest Volcanics in the eastern Rocky Mountains of Alberta.[1] They differ mainly in the absence of melanite, which occurs in the original blairmorite, and in the greater abundance of nepheline.

Blairmorite, originally named by C. W. Knight, was re-defined by J. D. MacKenzie as follows[2]: " A primary porphyritic volcanic rock, characterized by dominant phenocrysts of analcite in a matrix composed of analcite, alkali feldspar, and alkali-pyroxene, with titanite, melanite, and nephelite, not all of these groundmass minerals being necessarily present, and possibly others occurring. The rock on account of its ultra-alkaline nature will show numerous variations in texture and in proportions of component minerals, and the above definition has not been made more rigid on that account."

## RHYOLITE.

A lithoidal rhyolite, pinkish-buff in colour, occurs intercalated amongst the alkaline lavas some few hundred feet up from the base of the series along the course of the Minjobva River [N 691]. Under the microscope it is found to contain a few thin tabular Carlsbad-twins of orthoclase or anorthoclase as phenocrysts in an intensely altered groundmass full of extremely minute laths of felspar and patches of iron oxides. No free quartz was found. Drusy cavities are lined with small cubes of fluorite.

The rock next above this in the section is a breccia [N 692] with angular and subangular fragments of the underlying rhyolite. This also has crevices lined with fluorite. The fluorite is probably connected with the outcrop of nepheline-syenite which immediately succeeds the rhyolite and its breccia along the Penze to Chirisa track.

Alteration, possibly connected with the fluorine-bearing emanations, has affected some of the lavas in the alkaline series, making their exact identification extremely difficult. Thus rocks which appear to have been phonolites rich in the soda-amphiboles and aegirine are found in an intensely altered condition on the south of the nepheline-syenite referred to above. The ferromagnesian minerals are all converted into opaque iron oxide and cavities (? vesicles) in the lava are filled with dark purple fluorite [N 700]. In another of these lavas from the same locality the alteration has produced a bleaching effect so that the rock is full of spherical white patches which are found to be rich in fluorite [N 701].

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[1] MacKenzie (J. D.), " The Crowsnest Volcanics," *Canada Geol. Surv. Mus. Bull. No.* 4, Geol. Ser., No. 20, 1914, p. 19.

[2] Ibid., p. 27.

Another series of highly altered lavas and an interbedded tuff was found on the traverse from Bandar to Nkomadzi. These seem to be porphyritic pantelleritic trachytes. The felspar phenocrysts are much altered and partly replaced by carbonates or, in one instance [N 710], by chalcedony. This same specimen contains plates of quartz poecilitically enclosing the felspar laths of the groundmass: it has the appearance of having been a secondary deposition. Fluorite was not found in these rocks or in the tuff [N 707], but the joint-faces of one of the blairmorites from near Nkomadzi estate [N 710] are also coated with crystals of purple fluorite. A tinguaite [N 713, 714] outcrops in the immediate vicinity.

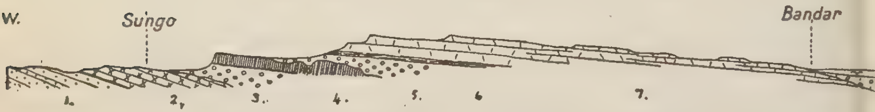

Fig. 1.—Rough Section North of Lupata Gorge from Sungo to Bandar. 1, Karroo Sandstone. 2, Karroo Basalt. 3, Lower Lupata Sandstones. 4, Rhyolite. 5, Upper Lupata Sandstones. 6, Sandy Tuffs and Agglomerate. 7, Alkaline Lavas. 8, Post-Lupata Sandstone. 9, Alluvium.

## PYROCLASTIC ROCKS.

Tuffs, some of which are similar in colour to those associated with the rhyolite series, form the base of the alkaline volcanics at one or two localities and are also found interbedded with the lavas.

On the Sungo-Garufa path there is a complete section from the rhyolites up to the alkaline lavas which are represented by the compact analcite-bearing phonolite [N 723] and the porphyritic blairmorite [N 724]. Above and below these lavas are beds of red sandy tuff [N 722 and 725], the lower one passing downwards into a very compact and exceedingly fine-grained lithic tuff, brick-red in colour, containing fragments up to 2 cm. across of dull-purple (dark livid-brown) rhyolitic lavas and smaller fragments of an opaque black glass with altered phenocrysts [N 726].

On the north-to-south traverse from Penze to Chirisa the series begins with a lithic tuff [N 685] with a vinaceous-drab groundmass enclosing fragments of felspar, pale glassy rocks, buff-coloured rhyolites, and black porphyritic rocks, possibly phonolitic. The ncluded fragments are partly converted into carbonate, the alteration affecting especially the felspars in the glassy matrix.

N 738 is a rather similar though darker coloured tuff from the base of the alkaline volcanics between Sungo and Changambika. The matrix seems to be a pale glass and contains abundant fragments of felspar and unidentifiable rock-fragments. Carbonate is extensively developed. Overlying this bed, as in the section in the same escarpment described above, is a red tufaceous sandstone, followed by the lavas.

Crystal tuffs [N 702, 704], very compact pale cinnamon-pink in colour and containing abundant salmon-coloured felspars, were collected from two beds near Chirisa on the track from Penze. They are intercalated amongst the lavas and like these have suffered considerable alteration and have been to some extent impregnated with fluorite.

Along the northern edge of the outcrop of alkaline volcanics, friable drab-grey tuffs underlie the phonolite of the Sarula scarp [N 418, 419]. They contain abundant fragments of altered glassy lavas and broken crystals of sanidine. In the upper bed [N 418] immediately below the phonolite the matrix is almost all converted into carbonate, but the sanidine crystals are unaffected. The original composition is entirely concealed and it is impossible to be certain from the hand-specimen whether this is a tuff or an altered lava. The underlying bed [N 419] is clearly a tuff with a very fine-grained, groundmass. A similar tuff [N 453], pinkish-cinnamon in colour, intervenes between the Sarula and Boku flows at the south-eastern end of the outcrop of alkaline lavas.

About half-way along the track from Penze to Chirisa, in the heart of the outcrop of the lavas, is a small mass of nepheline-syenite, which forms a ridge about a mile in length. Dikes of microfoyaite are associated with it. Again on the Bandar-Nkomadzi traverse a tinguaite with interesting spherulitic structures occurs in close proximity to the blairmorites. The relations of these rocks are not fully worked out and their description will be deferred for a later paper.

# The Theory of Dilatation, A New Theory of the Origin and Activity of Endogenous Forces: An Essay Review.

By Dr. J. MOSCHELES.

[KETTENGEBIRGE, KONTINENTALE ZERSPALTUNG UND ERDEXPANSION. By B. LINDEMANN. G. Fischer: Jena, 1927. The book discusses also the application of this theory to the regional tectonics of Central Europe and the Alps, though in the present paper we shall not enter into this subject.]

THE origin of orogenic forces including vulcanism is still a controversial problem of the borderland between geophysics and geology. The theory of contraction by the cooling of the earth's interior may be considered as the one fairly generally adopted by most European geologists, thanks to the authority of Eduard Suess, though unanimously rejected by geophysicists. In America, Dutton's theory of isostasy is usually considered to be able to explain the main reason for orogenic processes, though it might be pointed out that gravity anomalies occur just where endogenous forces were recently or are still most active on the surface, so that isostasy might be said rather to be perturbed by these forces than to call them forth.

More recently great importance has been attached to radioactive processes as the primary source of endogenous forces. J. Joly is of the opinion that the disintegration of radioactive matter in the earth's crust makes up entirely for the loss of heat by the cooling down of the earth, so that the radioactive heat of the underlying basic layers will accumulate and in time lead to a melting of these layers. As the density of molten lava is about seven per cent less than that of the solid form, the crust-blocks will plunge deeper into the substratum, the continents more than the sea-bottom, corresponding to the laws of isostasy. Such differential movements will produce vertical fractures in the border region between continental and oceanic areas, where eventually the molten magma may rise to the surface. Thus the thermal energy would be spent and then a rest stage would follow.

It is on fairly similar lines that Lindemann has built up his Theory of Dilatation, which, if not satisfactory all round, still seems to indicate a direction in which further investigations may come to interesting conclusions. According to him, the earth's crust is in a state of dilatation, thanks to its increasing calorification by radioactivity. It is only because calorification is a very slow process that the upper parts of the crust have not been liquefied in the time during which our globe has existed in its present shape.

An ever-increasing calorification would imply an increasing impulse to the activity of endogenous forces. Now, if one compares the "geosynclines", the folded areas of Palaeozoic and Tertiary times, the first seem to have been less extensive, and this might correspond to an increase of the endogenous forces in younger geological periods. This increase is still more conspicuous in volcanic activity. In geological history three epochs of maximum volcanic activity are known, the Keweenawan, Permian, and Tertiary maxima, three periods lying back according to some authors about 500, 200, and 25 million years respectively. Though the absolute time-valuations are open to doubt, the shortening of the intervals is at all events a reality and the greater frequency of the maxima in more recent times is again in keeping with the postulated increasing calorification of the earth. It has often been suggested that in our days volcanic activity has lost much of its former vigour and extension and that its present manifestations are but feeble reminiscences of Tertiary activity. But such periods of comparative inactivity occurred before, in Palaeozoic as well as in Mesozoic times, and it only means that we are living in the days of a descending branch of the curve of volcanic activity.

There remains to account for these ups and downs of the curves of both volcanic and orogenic activity on the surface of the earth. Disintegration of radioactive matter, heat production, dilatation and the transmission of force to the outer crust, and therefore volcanic and orogenic activity, ought to have always the same degree of intensity. But the gas and heat rising from the interior have first to pass the upper sima zone, where currents will be produced if only on account of differences of density and of outside pressure in this zone. Such currents, possible even in extremely viscous matter, will carry the overheated melt impregnated with gas to the areas of least resistance in the crust. Therefore centres of tension will develop in the sima zone, and when tension becomes sufficiently great, an explosion will take place and these masses rise. Such a vent or safety-valve once formed will continue in existence for a long time as it represents the easiest outlet for the influx from the interior. As, however, dilatation acts more slowly than discharge, tension and with it volcanic and orogenic activity will decrease until new accumulation of force; i.e. these activities will show a marked periodicity.

In this point, however, the author is not quite consistent: in one place he clearly shows that he thinks endogenous forces to be continuous just as depth orogenism. Only surface manifestations, surface tectonics, and surface volcanism, therefore processes restricted in space and depending on special circumstances, would be periodic. We shall return to this question.

In the configuration of the globe's surface two main levels may be distinguished. The one is represented by the level floors of the ocean basins at a depth of some 12,000 feet, the other at an altitude of about 600 feet representing, not the mean level of the continents, but the average height of their old " shields ", Archaean plateaus of sial composition.

There exists a fundamental difference between the composition of these two main levels as appears from gravity measurements, but they are very perfectly balanced according to the laws of isostasy. The continental sial blocks appear as something of a different nature lying on top of the sima masses under the ocean basins, and with Wegener it may be assumed that they drift on and in the sima.

Of the ocean floor but little is known. According to Lindemann, it would be composed of a stratosphere of sediments including sial fragments torn from the continental sial blocks and separated from the sima sphere only by a thin autochthonous sial zone. The sima sphere would be here in its upper parts solid, lower down latently fluid. No great denivellations seem to exist, while tectonic and volcanic activity are probably insignificant.

We are better informed about the continental sial blocks. These ancient plateaus have a but slightly undulating surface and in general lie but little above sea-level. Volcanic phenomena are scarce, earthquakes are rare or even unknown. These Archaean plateaus have a sial composition. On a substratum of granites, gneisses and metamorphic schists we find sometimes flat-lying and almost undisturbed sediments of a continental or epicontinental origin. Over large areas the crystalline rocks are directly exposed. And this sial crust existed at the dawn of geological history as an inheritance from still earlier times. This is proved by the fundamental unconformity with which even the oldest sediments rest on the primary crystalline rocks. This unconformity between the Archaean rocks and the base of the Precambrian sediments is universal.

There is much talk about a universal Archaean folding, though true Archaean folds have never yet been observed. What we see of disturbances are steep dip of the foliation, arching, and what Sederholm calls ptygmatic folds. Steep foliation is likely to be one of the primary features of the sial. The fluid rocks at a certain depth having not sufficient room for dilatation will acquire a parallel arrangement of their elements between the border-walls, so as to take up the least possible space. If these rock-masses were moving upwards, either vertically or at an angle, steep foliation may be considered as a fluidal structure. The arching seems to have been produced by rising magma; ptygmatic folds according to Sederholm[1] by magmatic injection, i.e. by fluctuations in the softened injected schists forming now apparently homogenous gneisses, though in truth with fine aplitic, pegmatitic, and other veins.

Therefore the structure of the sial crust would be primary, and the same might be supposed for its stability. According to its structure it would be the product of crystallization of melts rising from lower zones to the surface, where they probably spread. But these uppermost layers were since denuded and only the lower sial currents which have stiffened under pressure during their centrifugal movement, represent the building-material of the actual old "shields". This earlier period in which the planetary shell-structure was formed, may be called the period of sial genesis, and it is separated by the fundamental unconformity at the base of the Algonkian series from the actual period characterized by the destruction of the old stable crusts by dilatation, which may be called the period of orogenesis.

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[1] J. J. Sederholm, "Ueber ptygmatische Faltungen," *Neues Jahrbuch*, Beilage-Band 36.

Besides the two main levels of deep-sea plateaus and ancient shields, there exist, as a third element, more or less elongated zones, rift-valleys and deep-sea rifts, folded mountain zones and submarine ridges. They are characterized by features indicating great activity of endogenous forces: volcanoes, earthquakes, folding, and faulting of the rocks. Gravity anomalies show that in these zones isostasy is disturbed. They are not all, at least at the present moment, geosynclines in the proper sense of the word, but they form one great family of features for which a name—perhaps something like oroclines—has still to be found. Geosynclines may be folded up and attached as "new land" to the old shields, from which they differ in their much disturbed material including deep-sea sediments and heavy sima rocks, as well as by their strong relief, which makes us speak of them as of mountains. Then the variability of the sediments in a horizontal and vertical direction clearly shows that during sedimentation, during the true geosyncline stage in the proper meaning of the word, there was a side by side existence of ridges and depressions and an extreme mobility of these zones in a vertical direction.

Geology shows that during the known part of the history of our globe these labile zones increased at the expense of the stable ones: it seems as if the whole of the earth's crust were gradually becoming labile. That does not imply a decrease of the continental surface of the globe, as besides ancient shields present-day continents comprise new land-regions composed of geosynclinal deposits, not only on the surface, but also in depth. On the other hand, part of the sial blocks are covered by shallow epicontinental seas. The distribution of water and land has no direct relation to the extent of stable and labile parts of the earth's crust.

At present the old sial blocks occupy vast areas, especially in Eastern Europe and in Asia, in North America and in Africa with Arabia. In this part of the globe there is a distinct crowding of sial blocks, and if ever one great primary sial continent existed, it would have been in this region. At all events we see the gradual shattering of the existing sial blocks, for though they are comparatively rigid and stable and scarcely mobile, yet their stability is not perfect. Slowly and by forces working in the depths they are torn and divided into smaller blocks. It is in the sial blocks and not in geosynclinal new land that we find those great open fissures which on the largest scale are represented by the African rift-valleys. Their geosynclinal nature is indicated by gravity anomalies, gravity deficit in the East African rift-valleys, gravity excess in their prolongation, the Red Sea rift. The cracking of these rifts seems to begin at the surface and gradually to proceed downwards. No downfaulting of the rift-bottom takes place; vain attempts have been made to account for such supposed downfaulting between fault planes converging in depth, as for instance in the case of the Rhine-graben. Instead of such a downfaulting a tearing apart of the fault blocks along the fissure seems to be responsible for the formation of rifts. They are not downfaults, but are gaps in the sial crust, prepared by fissuring and produced by the drifting apart of the sial blocks.

Now below the young rift sediments the rift floor is formed by apparently downfaulted rocks, and in general the sides of a rift are wanting in symmetry, which might reasonably be expected in the two walls of one fracture. Both these objections, however, are easy to refute. From the fissured walls of the rift huge landslides, or rather blockslides, will go down into the yawning gap of the rift, and its bottom will be filled with fault-blocks which have nothing to do with endogenous downfaulting. The highest blocks will be thrown down deepest, other blocks less downthrown, and often older materials will be found higher up as we mount from the rift-bottom up across the stepfaults on its sides. These blockslides will also modify the walls. Besides, once a rift is formed, the two sial blocks are separated, each swimming by itself in the sima. Secondary uplifts combining with or following horizontal disjunction and later tectonic and volcanic pressures may affect only one of the two once continuous sial blocks. All this tends to obliterate the primary symmetry of the rift-walls.

The formation of such disjunctive rifts had recently been fully discussed by Krenkel,[1] who, however, expressly states that he does not consider the African rifts as a sign of the beginning of a drifting apart of two African continents. According to him, Africa as a whole is moving to the north-west, just as the Eurasian mass moves to the south and south-west, squeezing up between them the Mediterranean geosyncline. But the northward movement of the African mass over the plastic substratum encounters resistance, especially in its eastern half, and this leads to innercontinental fissuring and to horizontal displacements of neighbouring blocks.

But though the interpretations given by Krenkel and Lindemann differ, Lindemann agrees with Krenkel in regard to the mode of formation of the rifts. This interpretation may be summed up as follows: by longitudinal fissures an embryonal hollow of great length but small depth is formed. These longitudinal faults dip partly towards, partly away from the interior of the later rift, so delimiting tilted fault blocks. As disjunction proceeds, part of these fault blocks subside and form the bottom of the rift. The walls are fissured by the general slackening, the blocks divide into big slabs (just as the rocks do in tunnels as counter-pressure is removed), and along these fissures, all dipping towards the rift axis, these slabs slide down into the interior of the rift. In this way the step-fault structure of the walls is formed. At last disjunction attacks even these slab-blocks. New fissures are formed dipping mainly below the rift-walls. There are compensatory movements which may produce secondary folds, underthrusts, and warping of the rocks. But though these structures are mere surface features, the formation of the rift itself, disjunction, is an orogenic reality, and according to Lindemann dilatation in the earth's interior is the source of power for the drifting apart of the continents.

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[1] E. Krenkel, *Die Bruchzonen Ostafrikas*; *Tektonik, Vulkanismus, Erdbeben und Schwereanomalien.* Berlin: Borntraeger, 1922.

The primary cause of dilatation would be the hot gases of the interior, heavily compressed so that their rigidity is greater than that of cold steel. They have a correspondingly great tendency to dilatation, frustrated by the weight of the overlying masses. This gaseous zone is followed upwards by a less rigid magma layer, though even in its highest parts it is still extremely viscous. As isolation from the earth's surface is not absolute, the upper magmatic zone gradually loses its gas and sends even considerable quantities of molten material into the sial crust and even up to the surface. These losses are compensated by continuous inflow from below, where reduction of pressure produces dilatation, and such inflows will impregnate the upper magma layers with juvenile hot gases and raise their temperature. As these upper magma layers also contain radioactive material, no cooling down takes place and great expansive forces will develop even here. The hot upper magma, rich in gas, corrodes the solid crust, smelts it in part, and, pushed from below, rises into higher and higher regions. The lower magma follows, and as there is dilatation until a certain degree of comparative fluidity is reached, the upper calottes gradually become too small for the lower ones. Now the upper more fluid magma may expand laterally by melting down neighbouring rocks, so as to accommodate itself to the growing volume and surface of the lower magma. But the solid crust will be torn. In these fissures the upper magma will rise as far as pressure (dilatation) from below permits: therefore the opening of fissures is generally followed by volcanic activity.

Now, though the gas in the earth's interior strives to free itself, resistance is great, and huge, deep reaching fissures will not be produced easily. If, however, once a regional fissure belt is formed as a zone of least resistance, dilatation will concentrate on this zone and the magma from a larger area will flow together here. One might speak of a concentration of dilatation within a larger region, in this zone.

These additions of material from the earth's interior will result in a gradual pushing aside of the sial blocks from the fissure zone. Dilatation as manifesting itself on the earth's surface may therefore be divided into two components, a radial one of magmatic buoyancy and a horizontal one resulting in the lateral drifting apart of the continents (i.e. of the sial blocks).

It has been already said that at the bottom of a widening rift, surface tectonics will be most complicated by the sliding down of huge landblocks from the rift-walls. Some of these blocks will lie fairly horizontally, others will be tilted and some even overturned. Between these blocks igneous rocks occur, either juvenile or representing remolten parts of the crust with granitic character. When the sial blocks draw farther apart, the sima-zone is laid bare at the bottom of the bordering slopes (the former rift-walls), and the former rift-bottom with its filling of slide-blocks will then stand out as a long ridge, perhaps several hundred kilometres in width. Besides, magmatic buoyancy continues along the road once taken, new magma intrudes under the ridge which therefore expands. So the first or "protoanticline", of a later folded system is formed, composed in great depth of viscous sima magma, farther up of remolten gneisses and crystalline schists, the whole crossed by volcanic dykes. So the W-shape of the geosyncline is produced.

But when the continents draw still farther apart, magmatic buoyancy makes itself felt more and more in the two synclines, and less in the protoanticline, where weight increases. There is a reversal of magmatic currents, the protoanticline subsides, while the bottom of the synclines is gradually carried upwards. Eventually the protoanticline may even crumble and sink back as its substratum gives way, and then the geosyncline assumes an M-shape. This process may repeat itself until the bottom of the geosyncline may be said to resemble a sheet of corrugated iron.

A W-shaped geosyncline will give birth to a mountain-system with an anticlinal central zone of crystalline rocks, whereas from an M-shaped geosyncline a synclinal central zone of sedimentary rocks flanked by two crystalline zones will result, as in the Western Alps. A crystalline central zone may be also due to marginal cleavage of the sial continent, great blocks being isolated and eventually shattered into a shoal of outlying masses. Such sial-islands engulfed in the geosyncline may form the central zone of the Eastern Alps, and it is remarkable that throughout geological history these masses have retained the tendency to an elevated position as characteristic for sial blocks. The shattering into pieces (into the present individual crystalline mountain groups) of a long, comparatively narrow strip of sial blocks may be accounted for by axial undulation (cross folding), and such cross folding seems also to be indicated by the depth-conditions of the Southern Atlantic, of its ridge and deeps.

Magmatic processes having led to the formation of great anticlines and synclines, sediments will accumulate especially in the synclines, and that not only by sedimentation but also by sliding on the submarine slopes. Littoral sediments, sands and gravels, embedded between sediments of deeper waters, clays and limestones, may owe their present position to such slides. The active crustal movements in such very labile regions will cause the sliding down not only of still half-loose sediments on the surface, but sometimes also of lower solidified beds, so that older sediments may outcrop between younger ones (the " Aufbrüche " of the Alps). If the sediments are sufficiently plastic, slide-folds will be formed, and where they butt against resistant rocks, intricate though wholly superficial folded structures will be produced. Charriage, too, is nothing else but a sliding process under the influence of gravity on a slope produced by strong upheaval.

From an anticline where expanding forces concentrate, a lateral pressure will be exercised on the neighbouring synclines. As long as the sial blocks still draw apart, these synclines will be able to escape lateral pressure by following the movement of the blocks. The drift may cease and the whole process come to an at least temporary end, when the magma is turned off into a neighbouring geosyncline. It may also cease when a drifting sial block is arrested by another one blocking its way. In this case lateral pressure will manifest itself in compressing the syncline, its sediments being folded. The intensity of this folding will depend mainly on the character of the rocks ; rigid ones will be carried up *en bloc* out of the zone of pressure, piercing through their more plastic cover just as a salt-dome does. When the vertical component of dilatation has carried up a folded zone to a pressure-free level, folding ceases. When a sial block is pressed against another with a geosyncline in front, this, of course, is folded too, the Urals perhaps representing such a suture.

But it has to be remembered that all these foldings—in contrast to the formation of the great anticlines and synclines—take place on a substratum which does not fold, and at least in the autochthonous parts of folded mountains we see that even in sediments folds are far less frequent than fault-blocks and imbricated structures. Besides those already mentioned, there are still several other possibilities for the formation of surface-folds, for instance, folding produced at the base of overthrust folds (nappes de charriage), or by compression between heated and therefore expanding masses (sedimentary wedges in the crystalline rocks of the Western Alps). Further, it has to be noted that one and the same geosyncline may harbour simultaneously three zones differing in dynamics : (1) anticlines from which expanding pressure and slides issue ; (2) synclines under folding pressure, i.e. zones of compression ; and (3) synclines enlarging in the direction of a withdrawing sial block, i.e. zones of dilatation which if uplifted will form but little-disturbed plateaus within a heavily folded mountain-system.

Surface processes will reach their maximum only after that of the endogenous ones. The great slidings, foldings, and overthrusts will follow the maximum uplift of the anticline. In one and the same region surface orogenesis is therefore to a great extent a sequel to depth orogenesis. The same applies to surface volcanism in the great anticlines as, for instance, of the Caucasus, the Atlantic ridge, and the Andes. It is younger than the maximum intrusions, as the cones rise above local basins of lighter magma, such as could only form during the declining phase of magmatic ascent.

Lindemann speaks sometimes of an accumulation of interior forces spent in periodical paroxysms, but he speaks also of a continuity of magmatic processes and of the formation of primary broad anticlines and synclines. This would be more consistent with his theory as a whole.

Excessive uplift above the pressure zone and the formation of new rifts developing into geosynclines may divert magmatic activity into new channels, at least for a time. An effort would be made to re-establish isostasy : isostatic subsidence of the new land, producing perhaps epirogenetic uplifts of neighbouring blocks. Periodical would be, besides the locally restricted phenomena of surface folding and surface volcanism, the formation of new widening rifts, the gradual and growing consumption of the sial-crust by dilatation. With the submerged geosynclines continental splintering seems to advance into the deep-sea plateaus. That of the North Pacific is surrounded and peripherally dissected by such labile zones. As Lindemann says, we are watching the shattering of the earth's crust by internal dilatation.

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# Notes on Some Early British Graptolites.

By C. J. STUBBLEFIELD, Ph.D., A.R.C.S., F.G.S.

## I. PREVIOUS WORK ON THE SHINETON SHALE GRAPTOLITES.

FIFTY years ago Charles Callaway collected some graptolites from the Shineton (Tremadocian) Shales exposed in Mary Dingle (south of the Wrekin, Shropshire) ; these he recorded[1] as *Dendrograptus* sp., stating that he was unprepared to assign them "to any known species or to give them a new name". The fossils were sent to Charles Lapworth[2] who in 1879 (loc. cit.) wrote that they belonged to two different genera, *Clonograptus* and *Bryograptus* ; the *Clonograptus* he later identified[3] (loc. cit.) with reserve as *C. rigidus* Hall, whilst the *Bryograptus* formed a genosyntype for that then new genus. *Bryograptus* was defined by Lapworth[4] about this time from two new species—(1) *B. callavei*, collected by Callaway from the Shineton Shales, and (2) *B. kjerulfi*, of which Lapworth had only seen the figures (*Graptolithus tenuis*) which Kjerulf[1] had drawn from specimens found in the Alum Shales of Vaekkerö (near Oslo).

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[1] C. Callaway, *Quart. Journ. Geol. Soc.*, vol. xxxiii, 1877, p. 670.

[2] C. Lapworth, *Ann. Mag. Nat. Hist.*, Ser. v, vol. iv, 1879, p. 333.

[3] C. Lapworth, *Ann. Mag. Nat. Hist.*, Ser. v, vol. v, 1880, p. 274.

[4] C. Lapworth, *Ann. Mag. Nat. Hist.*, Ser. v, vol. v, 1880, pp. 164–5, pl. v, figs. 21*a*, 21*b*.

Lapworth distinguished the genus *Bryograptus* from *Dichograptus* and *Clonograptus*, " mainly in the fact that the secondary and tertiary branches are given off at irregular intervals, while the two chief [primary] branches instead of proceeding outwards in opposite directions make but a small angle with each other, composing an irregular polypary of an irregular dendroid form " (op. cit., p. 164).

By 1902, when the Elles and Wood *Monograph of British Graptolites* came to be published, the Scandinavian " Tremadocian " sediments had been zoned and their fauna more completely understood; accordingly the British authors were able to describe one of the Shineton Shale graptolites as *Clonograptus tenellus* (Linnarsson). Unfortunately they were unable to trace Lapworth's holotype of *B. callavei*, and with no truly comparable material at their disposal, the genus *Bryograptus* was not then recorded from the Shineton Shales. It was, however, apparently considered that a new variety of *C. tenellus* (Linnrs.) might be synonymous with Lapworth's *B. callavei*, and this new variety was denominated *C. tenellus* var. *callavei*. This variety was subsequently recognized in the Tremadocian deposits of Sweden[2] and of adjacent islands, as were other varieties of the same species. A related species, *Bryograptus hunnebergensis* Mbg., was also described as a prominent member of this same fauna in the *C. tenellus* Zone.

In 1927, a graptolite having affinities with *B. hunnebergensis* was recorded[3] from the Shineton Shales, and it is here thought probable that this is the form originally described by Lapworth as *B. callavei*. The case is not, however, considered sufficiently strong to advocate complicated changes in specific nomenclature.

## II. THE BITHECAE AND THEIR RELATIONS.

The purpose of this paper is mainly to give record of the finding of bithecae on specimens of three Shineton Shale Graptolites—*Bryograptus hunnebergensis* Moberg, *Clonograptus tenellus* (Linnrs.), and *C. tenellus* var. *callavei* Elles and Wood all occurring in the *C. tenellus* Zone and the Transition Beds below them.

Bithecae have not previously been described from these species, nor have they yet been definitely observed by the writer on material of similar specific aspect from localities other than those of Shropshire

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[1] T. Kjerulf, 1865, *Veiviser Christ.*, p. 3, figs. 6*a* and *b*.

[2] J. C. Moberg, and C. O. Segerberg, *Medd. Lunds Geol. Fält.*, Ser. B, No. 2, 1906, A. H. Westergård, *Lunds Univ. Årsskr.*, n.s., pt. ii, vol. v, No. 3, 1909, and C. Poulsen, *Danmarks Geol. Undersög*, Ser. IV, vol. i, No. 16, 1922.

[3] C. J. Stubblefield and O. M. B. Bulman, *Quart. Journ. Geol. Soc.*, vol. lxxxiii, 1927, pp. 111 and 118.

(e.g. the Wrekin area and Cardington Brook[1]) except in the case of *B. hunnebergensis* from the type Swedish locality.

Neither genus at present allows by definition for the accommodation of bitheca-bearing forms, but until well-preserved material of the other species has been examined it is deemed inadvisable to erect a new genus or genera. Since the presence of bithecae is

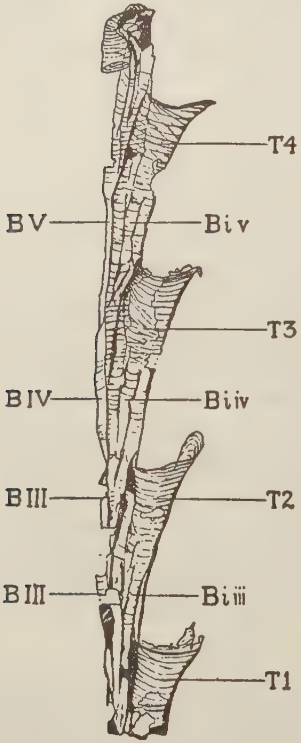

Fig. 1.[2]—Camera lucida drawing of a fragment of stipe belonging to *Clonograptus tenellus.* The specimen is preserved in yellow-brown chitin and the growth-lines are well seen.

T1, T2, T3, T4, Hydrothecae; Bi iii, Bi iv, Bi v, Bithecae; B III, B IV, B V, Budding individuals. (× 20.)

*Horizon.*—The *C. tenellus* Zone, north-easterly tributary of Cherme's Dingle, 115 yards above its confluence with Cherme's and 1,580 yards N.N.E. of Leighton Church, S. of the Wrekin, Shropshire.

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[1] C. J. Stubblefield and O. M. B. Bulman, op. cit., pp. 110, 111, 116.

[2] All text-figures in this paper are camera lucida drawings of specimens found in the Shineton Shales—south of the Wrekin, Shropshire—and have been given to the British Museum (Nat. Hist.) S.W. 7. The convention used in numbering the graptolite structures is such that the immediate descendants of one particular budding individual (e.g. III) carry the same numeral (IV, iv, 4).

essentially a dendroid character, it is considered that these finds strengthen the bridge which is already felt to exist between the early dendroidea and the early graptoloidea.

The Shineton Shale graptoloids are preceded stratigraphically by the dendroid *Dictyonema flabelliforme* (Eichw.), and the structure of this form has recently been described with full detail and illustration by Bulman.[1]

Here Bulman finds that as in later dendroids, the rhabdosome comprises three types of individual, " budding," bithecal, and hydrothecal (op. cit., 1927 p. 14). The " budding individual " gives origin to a hydrotheca, a bitheca and to another budding individual.

From his photographs of serial sections he deduces that " the bitheca appears rather before the separation of the hydrotheca and budding individual of the same generation, and opens beside the hydrotheca of the previous generation " (op. cit., 1927, p. 15). The budding individual, and bitheca together appear on alternate sides of the rhabdosome, and the alternating bithecae are readily recognized with a lens in suitably preserved material.

Bulman's work shows that this type of development is operative in *D. flabelliforme*, except where a stipe branches ; for there (op. cit., 1927, p. 17, fig. 7), a budding individual of the main stipe yields a bitheca and two budding individuals, of which the two latter diverge and each produce a new budding individual and a new hydrotheca but appropriate bithecae are not developed. The new divergent structures become the two resulting new stipes along which budding then proceeds in a normal manner.

During the course of the present work the specimen of *C. tenellus* drawn here as Fig. 8 was isolated from shale by the usual treatment with hydrofluoric acid, and mounted with Canada balsam on to a glass slide. Subsequent examination of this preparation demonstrated the presence of another fragment of stipe (labelled in Fig. 8 as " fr ") the external thecal characters of which show that it probably belonged to *C. tenellus*. The stipe fragment appeared fortuitously cleared as a transparency and a camera lucida drawing (Fig. 1) details its composition. Reflected light shows that the bitheca labelled Bi iv, opens on the " uppermost " side of the rhabdosome whilst Bi v and Bi iii open on the underside. The specimen examined by transmitted-light shows that the budding individual B III develops into a new budding individual B IV, a hydrotheca T 4, and a bitheca Bi iv which opens to the exterior by the side of another hydrotheca T 3 of the preceding generation of budding. The conformation of the growth-lines lends conviction to the present interpretation of the courses of the various individuals. In this species of *Clonograptus*, therefore, it seems that in the main stipe, at least, the development of the budding individual is substantially as in *D. flabelliforme*, and there is no evidence that it is different in *B. hunnebergensis*.

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[1] O. M. B. Bulman, 1925, Geol. Mag., pp. 50–67, text-figs. 1–12 ; and 1927, *A Monograph of British Dendroid Graptolites*, pt. i, Palaeont. Soc., London.

Since the sicula of the early graptoloids yields only two primary branches one would expect the development of these to resemble normal stipe-branching and generally speaking this is true. In *D. flabelliforme* the growth is essentially on this plan, but is somewhat complicated because of the formation of three or four early stipes instead of two. Bulman describes, however, in that form a bitheca which arises from the sicular bud, and, he states (op. cit. *supra* 1927, p. 18), it eventually " contracts rapidly . . . apparently without opening to the exterior ".

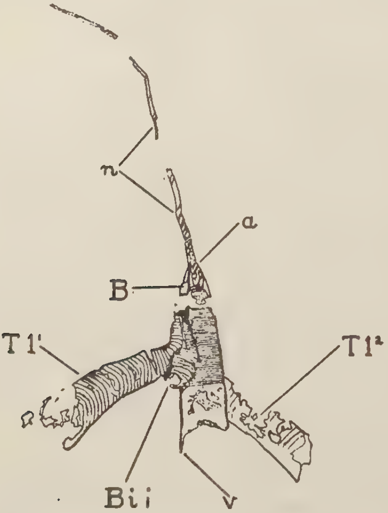

FIG. 2.—A sicula of *B. hunnebergensis* showing growth-lines, also a bud and a bitheca developed from the virgella side. (The specimen is preserved as a transparent film enabling growth-lines to be seen as drawn; elsewhere the specimen is opaque black.)

n, nema; a, " screw-line " ornamentation and " vertical strengthening " of the apical portion of the sicula and of part of nema; B, sicular bud[1]; Bi i, sicular bitheca; v, virgella; $Tl^1$, $Tl^2$, first hydrothecae of primary branches. (× 20.)

*Horizon.*—Near the base of *C. tenellus* Zone. Cherme's Dingle, left bank, 200 yards above its confluence with the Marrys Dingle, S. of Wrekin, Shropshire.

The homologue of this sicular bitheca (Bi i) has now been observed in both *C. tenellus* (Fig. 11) and in *B. hunnebergensis* (Figs. 2, 4, and 6), and in the latter at least (Fig. 2) it certainly appears to open to the exterior.

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[1] This would appear, from my drawing, to originate from the apical portion of the sicula about its junction with the apertural, but since the specimen is damaged in this region and the " apical portion " is completely opaque it is impossible to decide where the apertural portion really begins.

### III. BRYOGRAPTUS HUNNEBERGENSIS J. C. Moberg, 1892.
(Text-figures 2–7.)

1892. *Bryograptus ? Hunnebergensis* Moberg. *Geol. Fören. i Stockholm Förh.*, vol. xiv, pp. 92–5, 100, and 101, pl. ii, figs. 5–7.
1906. *Bryograptus Hunnebergensis* Moberg and Segerberg. *Medd. Lunds Geol. Fält.*, Ser. B, No. 2, pp. 61 and 62, pl. i, figs. 15, 16.
1909. *Bryograptus hunnebergensis* Westergård. *Lunds Univ. Årsskr.*, n.s., pt. ii, vol. v, No. 3, pp. 64–6, pl. v, figs. 10–21 and 23.
1925. *Bryograptus* sp. Bulman and Stubblefield. *Proc. Geol. Assoc.*, vol. xxxvi, p. 376.
1927 *? Bryograptus* cf. *hunnebergensis* Stubblefield and Bulman. *Quart. Journ. Geol. Soc.*, vol. lxxxiii, pp. 111 and 118.

This species is not infrequently found in the Shineton Shales in the *C. tenellus* Zone, and in the underlying Transition Beds. It was first described from beds of this horizon at the Swedish locality of Hunneberg. Through the kindness of Dr. A. H. Westergård, of the Swedish Geological Survey, I have been allowed to examine the three specimens on which Moberg based his species. Neither Moberg nor Westergård in their descriptions mentioned the presence of bithecae, nor are Moberg's paratypes well enough preserved definitely to show these, but a slightly better preserved specimen occurs on the same shale fragment as does that drawn by Moberg as pl. ii, fig. 5. This specimen is an undoubted *B. hunnebergensis* and carries bithecae on a second order stipe; other specimens on this same shale fragment show the sicular bitheca.

A generalized description based on the accounts of Swedish specimens given by Moberg and Westergård would read :—

> *Rhabdosome* declined. *Sicula* 1·0–1·5 mm. in length; right or left-handed. *Primary stipes*, angle of divergence 110–140 degrees; usually dichotomose after the opening of second or third hydrotheca, but one primary stipe may continue unbranched. *Secondary stipes*, one of these may continue line of the primary stipe; may branch again at some distance from primary stipes. Stipes of higher order than the third have not yet been found.
>
> *Hydrothecae* 9–10 according to Moberg, 10–11 according to Westergård in 10 mm. (The type specimens show this number to be 9–10, C. J. S.); overlap to one-half their length; outer walls slightly concave; apertural margins slightly concave and nearly at right angles to dorsal edge of stipe.

To this one would add that bithecae are present, growing on alternate sides of the rhabdosome.

The following notes are based entirely on Wrekin Shineton Shale material :—

#### (*a*) *Development.*

The sicula may have a long hollow nema (Fig. 2), which in the middle part of its course and particularly as it reaches the apical part of the sicula shows transverse grooves; these are homologous with the "Schraubenlinie" or screw-lines described by Kraft[1] in the sicula of *Diplograptus* and *Monograptus* and the presence of homologous "Langverstärkungsleisten" or vertical strengthening supports is suggested in the apical portions of the sicula and in that part of the nema adjoining. Slightly distal from where the nema and the sicula merge, the sicular bud B appears to take origin, on the virgella side of the sicula. The succeeding parts of the sicula show a series of very closely set growth-lines, about forty being counted in a space of 0·5 mm. The bud grows fixed to the sicula for what can be but a short distance and then gives rise to a bitheca, Bi i, and apparently also to two buds each of which rapidly divides into a hydrotheca and a new bud; the pairs separate at an angle to form the primary stipes. It may be noted that the growth-lines of the hydrothecae and of the distal regions of the sicular bud are wider spaced and more conspicuous than those of the sicula. As in *D. flabelliforme*, one of the primary stipes may cross the sicula, either to the right, or to the left-hand side, the sicula is then for purposes of description termed respectively right- or left-handed.[2]

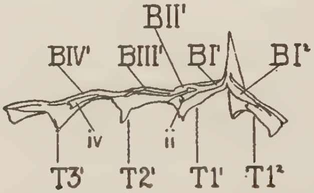

FIG. 3.—Antisicular (reverse) side of a right-handed sicula of *Bryograptus hunnebergensis*.

B $I^1$, B $I^2$, B $II^1$, B $III^1$, B $IV^1$ are buds; T$1^2$, $1^1$, $2^1$, $3^1$ are hydrothecae and ii and iv represent bithecae. (× 7·5.)

*Horizon.—C. tenellus* Zone, Cherme's Dingle, 70 yards above its confluence with the Marrys Dingle and 1,170 yards N.N.E. of Leighton Church, S. of the Wrekin, Shropshire.

The above figure shows the left-hand primary stipe leaving the sicula at an angle of approximately 100 degrees; at this stage the stipe consists of a hydrotheca (T $1^1$) and a bud (B $I^1$). A little over half-way along the course of the hydrotheca the bud divides to yield a new bud, B $II^1$, and a new hydrotheca, T $2^1$, and a bitheca ii. The bitheca opens alongside the previously existing hydrotheca,

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[1] P. Kraft, "Ontogenetische Entwicklung und Biologie, von *Diplograptus* u. *Monograptus*." *Pal. Zeitsch.*, vol. iii, 1926, p. 223.

[2] Graptolites are usually figured with the sicular aperture facing downwards, and since the nema forms the proximal end, the right-hand side of the animal is by this convention drawn to appear on the left. The terminology "right-handed" and "right-hand stipe" adopted in this paper is therefore morphologically incorrect but with the conventional drawing-position, this usage seems less likely to confuse the reader.

T $1^1$, on the antisicular side of the rhabdosome, whilst as further budding continues along the stipe the bithecae appear on alternate sides. It is noticed, however, that bitheca iv takes origin at a relatively earlier period than does bitheca ii.

The bud B $I^2$ and the hydrotheca T $1^2$ of the right-hand primary stipe together run forwards and outwards to the right, across the sicula, leaving the left-hand stipe at an angle approaching 110 degrees, and having acted as " a crossing canal " they leave the sicula. Budding then proceeds as in the left-hand stipe except that the first bitheca of the stipe (ii$^2$) does not appear on the anti-sicular side.

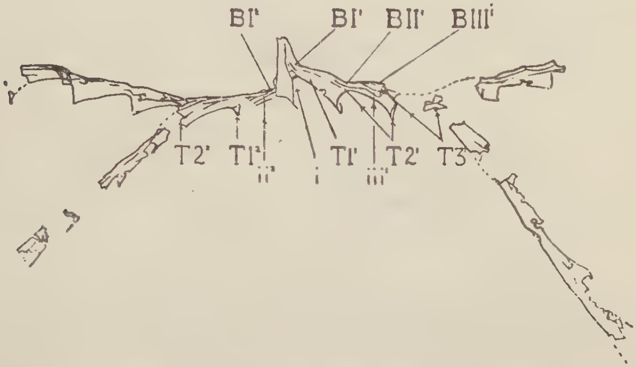

FIG. 4.—Sicular (obverse) side of a right-handed sicula of *B. hunnebergensis*; an average sized rhabdosome showing secondary branching. The upper of the two left-hand stipes is twisted in the neighbourhood of the second hydrotheca.

i is the sicular bitheca, the other symbols are as in Fig. 3. (× 7·5.)

*Horizon.—C. tenellus* Zone, Lady Covert Dingle, 100 yards below its bifurcation which occurs 2,100 yards N.E. of Leighton Church, Wrekin, Shropshire.

A view of the sicular side of the rhabdosome (Fig. 4) shows that the bitheca ii$^2$ does appear on this side, as does the sicular bitheca; and also bitheca iii$^1$ of the opposite stipe, here seen on the right-hand side. It is also seen that the second of the primary stipes after leaving the sicula increases its divergence angle to about 140 degrees; this angle may be somewhat greater in some specimens.

Figs. 5 and 6 are representations of the species showing the more familiar left-handed primary branching. The development is substantially as in the right-handed type already described, and Fig. 6 shows that a third generation bitheca (iii$^1$) arises relatively earlier than does the second generation bitheca (ii$^2$). Higher in the zone (Fig. 5) this is not so apparent.

The first order stipes frequently tend to branch dichotomously after the second or third hydrothecae have opened, i.e. 2·0–2·5 mm from the sicula; it is unusual, however, for the two primary stipes to be of similar length. Only infrequently are second order stipes found continuing to a bifurcation; in the specimen figured (Fig. 7) such occurs at distances 15–20 mm. from the secondary bifurcation (judging from figures given by Westergård, in the Swedish material this distance does not exceed 9·0 mm.). The third order stipes may attain such lengths as 22–23 mm., and on division yield small stipes of the fourth order.

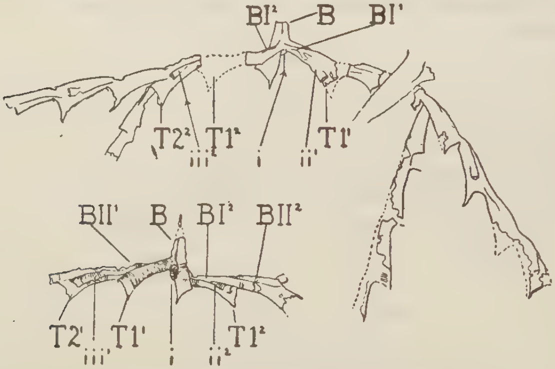

Fig. 5.—(The uppermost specimen) Antisicular (reverse) side of a left-handed sicula of *B. hunnebergensis*; an average sized rhabdosome.

Fig. 6.—(The lower specimen) Sicular (obverse) side of a left-handed sicula of the same species; the specimen shows growth-lines.

*Horizon.—C. tenellus* Zone, Cherme's Dingle, Wrekin, Shropshire. Specimen drawn as Fig. 5 was collected from the stream 45 yards above its confluence with the Marrys Dingle and 1,150 yards N.N.E. of Leighton Church, at a somewhat higher stratigraphical level than that of Fig. 6, which is the locality of specimen Fig. 2.

Symbols are as in Fig. 3. (×7·5.)

### (*b*) *General Characters other than Branching.*

The stipes, especially those of the higher orders, appear to be flexuous, and, measured across the hydrothecal aperture, attain a breadth of 0·5–0·7 mm. Isolated stipes have been collected showing a breadth of 1·0 mm., but it is not absolutely certain that these pertain to the species now under consideration. The sicula, excluding the nema, is usually 1·2 mm. in length. The hydrothecae number 8–10 in 10 mm., with slightly concave ventral walls, making in their normal state of compression an angle of 30–35 degrees with the dorsal wall of the stipe, which itself tends towards concavity opposite the thecal apertures. This aperture may show a slight spine. The hydrothecae are larger and more sparsely distributed than in *D. flabelliforme* (where the number is 14–16 in 10 mm.), but they are almost indistinguishable from those of *C. tenellus*.

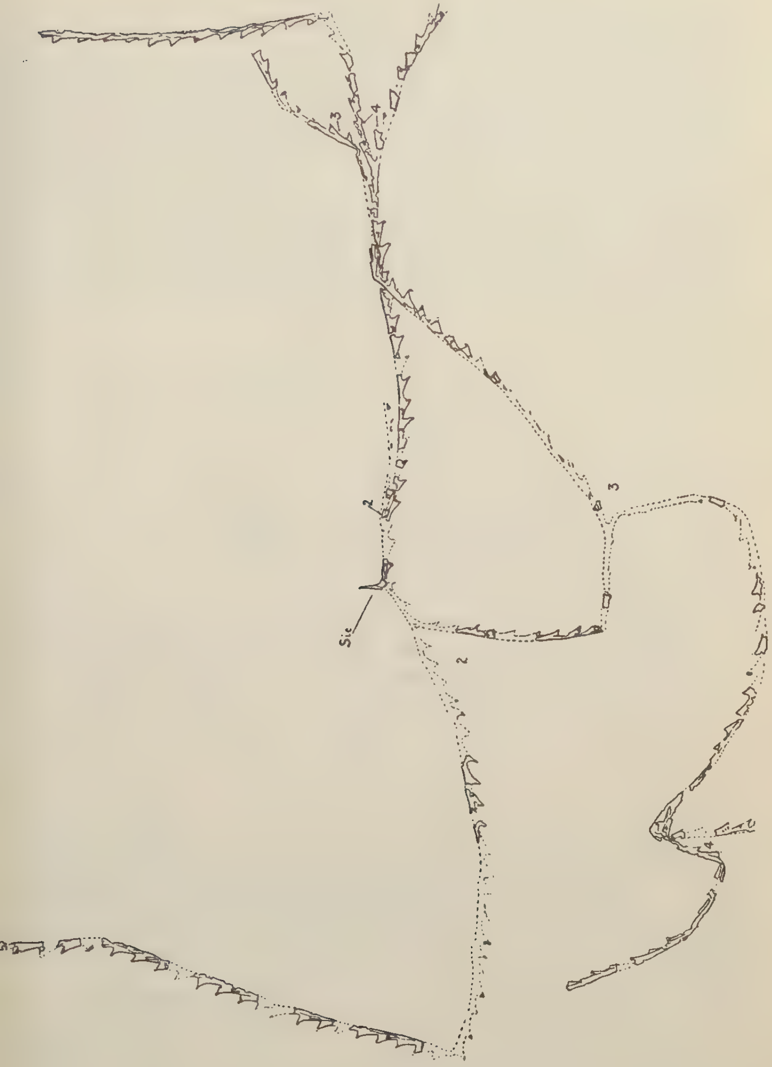

FIG. 7.—An unusually large individual of the same species showing bithecae and branching to the fourth order (the numbers placed at the stipe bifurcations indicate the degree or "order" of the branching). The specimen exists in counterpart; the dotted lines indicate the impressions left in shale by the graptolite. (× 2·5.)

*Horizon.*—*C. tenellus* Zone, The Marrys Dingle (Mary Dingle of early writers), 120 yards below the entry of Cherme's Dingle and 1,030 yards N.N.E. of Leighton Church, S. of the Wrekin, Shropshire.

The bithecae appear to be of the general *D. flabelliforme* type as described by Bulman (op. cit., 1927), and they apparently develop in a similar manner ; they are of cylindrical form, and open to the exterior usually at distances of half to two-thirds the length of the free portion of the adjacent hydrotheca. There is a tendency, in specimens coming from the stratigraphically early horizons, for the bithecae to open nearer the apertures of the adjacent hydrothecae, particularly in the proximal regions of the rhabdosome. Generally speaking, the Shropshire material agrees well with that from Sweden, with the possible exception that some of it may be more robust, and occasionally, but by no means frequently, it may show a greater tendency to branch. Multiple branching is not a usual feature in either form.

## IV. CLONOGRAPTUS TENELLUS (Linnarsson) *forma typica.*

(Text-figures 1 and 8–11.)

1871. *Dichogr.* (?) *tenellus* Linnarsson. *Öfv. Kongl. Vet. Akad. Förh.*, vol. xxviii, No. 6, p. 795, pl. xvi, figs. 13–15.
1892. *Clonogr. tenellus* Moberg. *Geol. Fören. i Stockholm Förh.*, vol. xiv, pp. 89–92, pl. ii, figs. 1–3.
1902. *Clonogr. tenellus* Elles and Wood, E. M. R. *Mon. Brit. Graptolites*, Palaeont. Soc. Lond., pt. ii, p. 83, pl. xi, figs. 2*a*–*c*.
1906. *Clonogr. tenellus* (*forma typica*) Moberg and Segerberg. *Medd. Lunds Geol. Fält.*, Ser. B, No. 2, p. 60, pl. i, fig. 8.
1909. *Clonogr. tenellus* (*forma typica*) Westergård. *Lunds Univ. Årsskr.*, n.s., pt. ii, vol. v, No. 3, p. 68, pl. iv, figs. 17–18, 22 and 24.

The species was first described from Nygård, near Hunneberg, but not until 1892 was its stratigraphical horizon correctly given ; it now serves as an index fossil of the Tremadocian of Britain and Scandinavia. Specimens were described from the Shineton Shales[1] by Elles and Wood (loc. cit. *supra*), and the diagnosis and outline description given there still hold good, but more varied material brings to light new information.

Isolation with hydrofluoric acid gives the more unusual view of the underside of the graptolite rhabdosome (Fig. 8), and shows clearly that bithecae are present and continue to be developed up to the sixth or last developed order of branching and to the natural termination of a stipe (e.g. top of Fig. 8).

As in *D. flabelliforme* and in *B. hunnebergensis*, the bithecae open on alternate sides of the succeeding hydrothecae.

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[1] There is no doubt of the specific identity between the English and Swedish material.

### (*a*) *Development.*

Specimens showing a perfect sicula are rarely preserved, for most *Clonograpti* rest with the apertures of the early formed thecae directed into the shale, and the sicula lies in a plane normal to the bedding. Sometimes, however, the sicula has been tilted slightly from the normal, then needle excavation, preferably performed under liquid varnish, may lay clear the details of the sicula and the thecae. During this operation, the shale debris should be repeatedly brushed away with a fresh application of varnish.

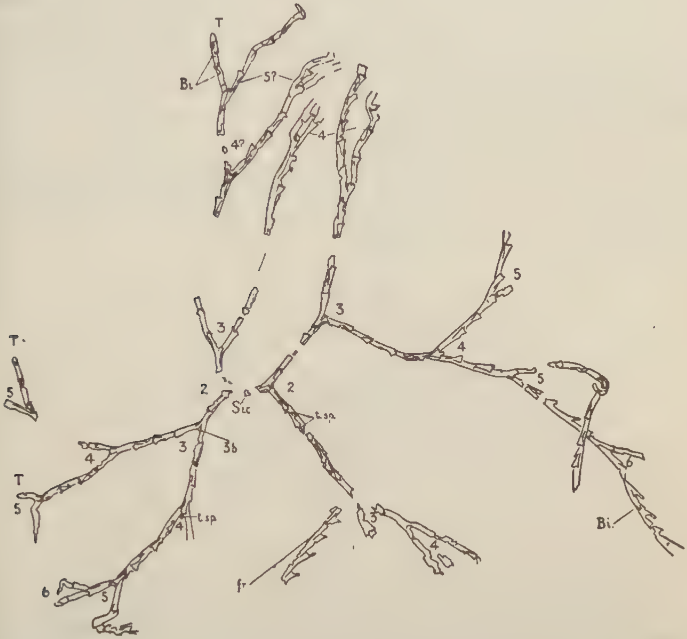


Fig. 8.—A fairly complete isolated specimen of *C. tenellus*, showing branching to the sixth order with bithecae (Bi) on stipes of all orders.

Sic., Sicula; T, termination of stipe; t.sp., "apertural spines" of hydrothecae; the numbers indicate the order of branching: 3*b*, web or linkage structure developed in a third order bifurcation; fr., fragment of stipe enlarged as Fig. 1. (× 2·5.)

*Horizon.*—*C. tenellus* Zone, north-easterly tributary of Cherme's Dingle, locality as for Fig. 1.

The early development appears to be essentially as in *B. hunnebergensis*, with one important difference—i.e. the linking of the two primary stipes and their subsequent straight alignment as opposed to the relative angularity seen in *B. hunnebergensis.*

In both species, too, the primary stipe may be either right- or left-handed (see p. 273).

Fig. 9 shows a left-handed sicula with a sicular bud B, dividing to yield the two primary stipes. The bud B forms the sicular bitheca (see "i" Fig. 11), and presumably also two budding individuals which quickly yield respectively (1) the right-hand primary stipe composed of BI$^1$ and T1$^1$ and (2) the left ("crossing canal") primary stipe, composed of BI$^2$ and T1$^1$. There is also a web-like structure labelled "1*b*" linking BI$^2$ and BI$^1$ across the sicula. The morphology of this structure is perhaps better understood when one examines the normal stipe branching in *C. tenellus* and its varieties, which, however, will be considered later (see p. 282).

The right-hand stipe shown in Fig. 9 leaves the sicula at an angle approaching 70 degrees, and the budding individual BI$^1$ eventually gives origin to a new budding individual BII$^1$, a new hydrotheca T2$^1$ and a bitheca ii$^1$, which opens near the aperture of T1$^1$ on the antisicular side of the rhabdosome.

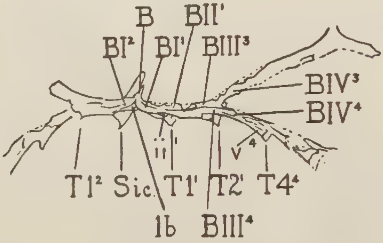


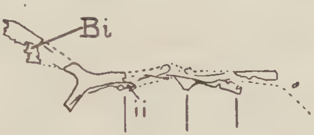
Fig. 9.—Antisicular (reverse) side of a left-handed sicula of *C. tenellus*. Symbolization on the plan of Fig. 3 with the addition of 1*b*, the "linkage structure" or web between the primary stipes. (× 7·5.)

*Horizon.*—"Transition Beds," Cherme's Dingle, 315 yards above its junction with the Marrys Dingle and 1,420 yards N. of Leighton Church, S. of the Wrekin, Shropshire.

The left-hand stipe crosses the sicula, leaving it at an angle of about 110 degrees, thus after leaving the sicula, the two primary stipes lie as one straight line. It will be seen that here, while the left-hand primary stipe bifurcates at the level of the first hydrothecal aperture (an exceptional occurrence in *C. tenellus forma typica*), the right-hand stipe does so at the level of the second (T2$^1$). The details of the branching are not very clearly seen in this specimen.

Second order branching in *C. tenellus* (*forma typica*) usually takes place opposite the aperture of the second or less frequently the third hydrotheca, as seen in Fig. 11. This specimen gives some idea of the details of branching, but unfortunately the specimen is not free from cracks where one least wishes them.

It seems safe to state that a budding individual, here BIII$^1$, gives origin presumably to a bitheca (IV$^1$ on the antisicular side of the rhabdosome), and to two new budding individuals (BIV$^3$ and BIV$^4$) which grow together until bifurcation starts ; here, each budding individual divides to form a hydrotheca and new budding individual of the fifth generation (T5$^3$ and BV$^3$ in the upper branch and T5$^4$ and BV$^4$ in the lower branch), but in each case the potentiality must exist for the formation of a bitheca. The preceding or fourth generation, however, yielded no hydrotheca against which a fifth generation bitheca could be opposed—the resulting structure in the fifth generation is a small binding web, 2*b*, linking proximally the two new secondary stipes which is truly homologous with the web 1*b*, uniting the first order stipes across the sicula (see Fig. 9). Thus the bitheca which in *Dictyonema* sometimes formed strengthening dissepiments from stipe to stipe of the dendroid rhabdosome (Bulman, op. cit., 1927, pp. 21–22) may be modified and developed locally for a similar strengthening function, but in a different position, to serve in a rhabdosome where there are many branches growing horizontally. These "webs" are not found throughout the *C. tenellus* rhabdosome, but they are well developed in the variety *C. tenellus callavei.*



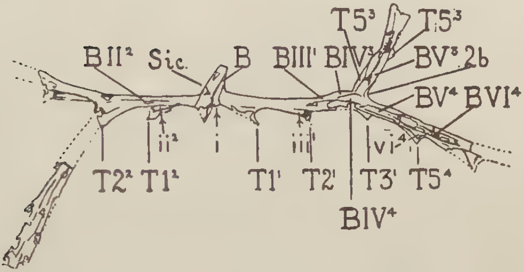


FIG. 10.—(Uppermost specimen) Antisicular (reverse) side of a right-handed sicula of the same species, showing the fragmentary and a more usual preservation of the sicula.

*Horizon.*—Transition Beds, Cherme's Dingle, about 7 yards upstream from locality of Fig. 2.

FIG. 11.—(Lower specimen) Sicular (obverse) side of a right-handed sicula of *C. tenellus forma typica*, showing a sicular bitheca (i).

*Horizon.*—A low level in *C. tenellus* Zone, Cherme's Dingle (locality as for Fig. 2), Wrekin, Shropshire.

Symbols as in preceding figures, with the addition of 2*b*, which indicates "the linkage structure" of the right-hand second order stipes. (× 7·5.)

### (*b*) *Other Characters of " C. tenellus ".*

The sicula, as known at present, does not exceed 1·2 mm. in length, and may be only 1·0 mm.; when preserved it always lies at an angle of 65 degrees or 70 degrees to the " funicle " (the united primary stipes). The funicle varies in length from 2–4·5 mm. The angle of divergence of the stipes naturally varies with the degree of flexibility, and more particularly with the position in which the rhabdosome has come to rest; usually the angle varies from 180 degrees or less in the first order stipes to 45 degrees in the seventh order stipes. Seventh order branching is the highest known to the writer in Shineton Shale material. At a bifurcation the resulting stipes are not necessarily even approximately equal in length, particularly in the fourth and later orders of branching, but one of the stipes is practically always longer than the stipe from which it originated, except in immature or terminal branches where growth has not been completed.

The hydrothecae normally number 8–10 in 10 mm., but in certain fourth and fifth stipes of one specimen eleven thecae occur in that distance, the normal distribution being seen on those other stipes where thecae are visible. At a hydrothecal aperture the stipe is typically 0·5–0·6 mm. in breadth.

The bithecae of specimens collected from the Transition Beds and the lower levels of the *C. tenellus* Zone open much nearer the hydrothecal apertures, particularly in the proximal parts of the rhabdosome, than do those collected from higher levels. This feature is shared with *B. hunnebergensis*. The typical horizontal growth of *Clonograptus* as opposed to the pendent habit of *Bryograptus* renders the smooth stipes of the first genus, apparently barren of thecae readily distinguishable from those of the latter, but in the distal parts of the *Clonograptus* rhabdosome the stipes are usually preserved turned on their sides; while it is easy to distinguish complete specimens belonging to either genus, in the two species under consideration the hydrothecae are very similar, but perhaps those of *C. tenellus* are more strongly spined ventrally; luckily the early stages of both species differ and, in *B. hunnebergensis*, branching is infrequent and erratic, but unless these points can be examined it may be difficult to tell fragments of the two species apart.

### V. CLONOGRAPTUS TENELLUS var. CALLAVEI. Elles and Wood.

1880. *? Clonograptus rigidus* Lapworth. *Ann. Mag. Nat. Hist.*, Ser. v, vol. v, p. 274.

1883. *Bryograptus* cfr. *B.* (*Dichograptus*) *flexilis* Tullberg. *Zeitsch. d. Deutschen Geol. Ges. Jahrg.*, 1883, p. 247.

1892. *Bryograptus ? sarmentosus* Moberg. *Geol. Fören. Stockholm Förh.*, vol. xiv, pp. 56, 96, pl. ii, figs. 10–12.

1902. *Clonograptus tenellus* var. *callavei* Elles and Wood. *Mon. Brit. Grapt.*, Palaeont. Soc. Lond., pp. 84–5, pl. xi, figs. 3*a*–*c*.

1906. *Clonograptus tenellus* var. *callavei* Moberg and Segerberg. *Medd. Lunds Geol. Fält.*, Ser. B, No. 2, pp. 60, 61, pl. i, figs. 9 and 10.
1909. *Clonograptus tenellus* var. *callavei* Westergård. *Lunds Univ. Årsskr.*, n.s., pt. ii, vol. v, No. 3, pp. 698–70, pl. iv, figs. 1–13; pl. v, fig. 2.

It is perhaps unfortunate that this variety has not been permanently referred to as *C. tenellus* var. *sarmentosus* Mbg., and that the specific name *callavei* has not been reserved for the species of *Bryograptus* which Lapworth made one of his genosyntypes (see p. 268); the figures of the now missing type specimen given by Lapworth [1] are difficult to interpret and its locality "Cound Brook" is unlikely to be correct [2] yet it is clear that Lapworth could distinguish his genus *Bryograptus* from *Clonograptus*.

This variety differs particularly from the *forma typica* in showing a tendency for the adult rhabdosome to cover a smaller area more compactly; a condition effected by wider stipes branching at shorter intervals and having more prominent "webs" uniting the bifurcating stipes proximally.

Transition forms occur between this variety and the *forma typica*, all showing bithecae. The rhabdosome grows horizontally with the sicula usually preserved in a plane at right angles to the bedding of the shale; consequently one may observe a broken projection located near the centre of the funicle or in a mould of the funicle one may find centrally a pitted imprint.

The funicle, or united primary stipes, has a length of 1·5–3·0 mm., and is usually preserved as a perfectly straight line. The secondary stipes have an average length approximately similar to that of the funicle. Stipes of the third order are more variable in length, sometimes averaging little more than the secondary, sometimes nearly twice that length. Stipes of higher orders, though usually relatively longer, still show great variations in length ratios. Stipes have been observed in Shineton Shale specimens occurring up to the sixth order (Westergård figures a Swedish specimen showing seventh order stipes).

The funicle may be 0·5 mm. in breadth (even where no details of the thecae are visible) and stipes of the second order at their divergence may yield a surface 1·0 mm. in breadth (dorsal surface of stipe only); the angle between the diverging stipes is bevelled by the "web" of which a less extensive form has been described in *C. tenellus* (p. 281). Similar webs are developed to a progressively less degree certainly as far as the fifth order. Judging from the figures of Swedish specimens (Westergård, op. cit., 1909, pl. iv, figs. 1, 3, 4, 8, and 10), this web may be produced distally to border the "inner edges" of the stipes; such a flange bordering the funicle may give it a breadth which can exceed 1·0 mm., whilst the flange may continue distally to border the "outer or opposite" edge of the webbed stipe. The flange and webs apparently lie horizontally and at right angles to the plane of the hydrothecae; they are compared by Westergård with the discus of some Dichograptidae, and as with these, the structure may be present or absent in individual specimens of the particular species.[1] The flanges have not been observed in the Shineton Shale material, but it would be interesting to see their relation, if any, to the bithecae.

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[1] Lapworth, , *Ann. Mag. Nat. Hist.*, Ser. v, vol. v, 1880, p. 165, pl. v, figs. 21*a*, 21*b*.

[2] In *Mon. Brit. Grapt.*, Palaeont. Soc. London, pt. ii, 1902, pp. 84–5, it was stated that Lapworth described *B. callavei* from Mary Dingle. It is likely that the specimen came from this locality, but Lapworth's paper reported the species from Cound Brook—the Shineton Shales of Cound Brook yield no graptolites.

The Shineton Shale stipes of high orders tend to decrease in breadth distally, a character by no means absent from the figures of Swedish specimens given by Westergård.

*The thecae.* Bithecae and budding individuals are present and are of the type already described in the *forma typica.* The thecae are, however, rarely visible as opening structures in the complete rhabdosome, unless the specimen is isolated with acid. The hydrothecae vary in their distribution from 8–10 in 10 mm.; they overlap from ½ to ⅓ of the exposed part of the contiguous theca. They are very similar to those of the *forma typica*, but are perhaps more robust; the usual breadth of the stipe at a hydrothecal aperture is 0·7 mm., sometimes a little more.

*C. tenellus* var. *callavei* occurs usually in association with the *forma typica* and with *B. hunnebergensis* in the *C. tenellus* Zone and in the Transition Beds of the Shineton Shales. It is also known from the Calvert Boring (Bucks).

## VI. SUMMARY AND GENERAL CONCLUSIONS.

Notes are given on two Shineton Shales species of graptolites typically found in the *C. tenellus* Zone of the Wrekin district, Shropshire: *Bryograptus hunnebergensis* Moberg, and *Clonograptus tenellus* (Linns.), with its variety *C. tenellus* var. *callavei* Elles and Wood; the first of these species is recorded from Britain for the first time. It is demonstrated that these three forms bear bithecae and budding individuals of the type recently described by Bulman in *Dictyonema flabelliforme* (Eichw.). The early development of the two species is discussed, and it is shown that in these the *Clonograptus* sicula differs from the *Bryograptus* sicula in the possession of a web or linkage structure uniting the primary branches which themselves lie in direct linear continuation. This web structure is well developed in branching of *all* orders in *C. tenellus* var. *callavei*, and less so in the *forma typica*. It is shown that the " crossing or connecting canal " is not simple as it would appear to be from the chitinised structure seen in the typical two-branched graptolite, but is composed of a budding individual and a hydrotheca.

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[1] Nicholson (*Mon. Brit. Grapt.*, Pal. Soc. London, pt. i, 1872, p. 67) compared the Dichograptid discus with the "float" of modern Physophoridae, and further quoted Hall's description of *Tetragraptus* (*Graptolithus*) *alatus* in which the discus is prolonged "along the margins of the stipes producing an alation"—a structure homologous with the flange of the Swedish *callavei.*

From the great similarity of structure of the two species, it is concluded that they were derived from a common stock which was not unremotely connected with that to which belonged the pendent dendroid *Dictyonema flabelliforme*. The pendent Bryograptid here considered, shows no great tendency towards multiple branching, whilst the horizontally growing *Clonograptus* with its stipes strengthened proximally by a web, appears capable of branching to a considerable degree.

Much could be said in favour of classing these species with the Dendroidea; it will, however, be left for later work to decide whether all, or merely other, species of these genera are to be similarly relegated.

It is considered likely that examination of well-preserved material of such species will reveal in many cases the presence of bithecae and budding individuals, as also may examination of others of the multiple branched Dichograptid genera.

Even *Didymograptus* is not always as simple in the chitinised structure of its rhabdosome as one is tempted to suppose, for Holm[1] has figured a mutation of *Didymograptus minutus* Törnq., where judging from the figure given (op. cit., fig. 3), the proximal portion of the first primary stipe is composed of a budding individual and a hydrotheca and the crossing canal is possibly similarly constructed.

Before concluding I would thank the Director and Dr. A. H. Westergård, of the Swedish Geological Survey, for their kindness in lending me the type specimens of *B. hunnebergensis* for examination, and also the Director and Mr. J. Pringle of H.M. Geological Survey, for the loan of their *Clonograptus* material from Cardington Brook, Shropshire.

To Dr. G. L. Elles, Professor W. W. Watts and Dr. O. M. B. Bulman I am deeply indebted for reading the manuscript and for helpful suggestions.

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[1] G. Holm, *Geol. Fören. Stockh. Förh.*, vol. xvii, 1895, pp. 332–4, pl. xi, figs. 1–3, and GEOL. MAG., 1895, pp. 440–1, pl. xiii, figs. 1–3.

# REVIEWS.

THE OLD COTTAGES AND FARMHOUSES OF NORFOLK. By C. J. W. MESSENT. pp. 248, with numerous illustrations. Norwich: H. W. Hunt. 1928. Price 10*s*.

THE main interest of this book, as its title indicates, is architectural: it contains descriptions and admirable drawings of a great number of old buildings in the Norfolk villages and countryside, of the type which is now so rapidly disappearing in many parts of England. The building-materials available in that county are in some ways of peculiar character, owing to the absence in most parts of good stone, and the author shows considerable interest in their nature and origin, especially on the geological side. He gives a really good special chapter to the Carstone, which is the one notable building-stone of the county and has been used with such excellent effect in its western part in that beautiful stretch of country between Castle Rising and Hunstanton, so well known to geologists.

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TECHNISCHE GESTEINKUNDE. By J. STINY. 2nd edition. pp. vii + 550, with 1 coloured plate, 422 text-figures, and appendix in pocket of cover. Vienna: Julius Springer, 1929.

THIS book is a second edition and such do not usually require extended notice, but the reviewer has no recollection of having seen the first edition, so a brief account of its general scope may be given. The work is primarily intended for engineers, quarry-owners, agriculturalists, and so on: consequently a large part of it is occupied by technical details, tables, and descriptions of machinery. But the first 380 pages are devoted to geology and petrology, from the scientific standpoint; this is well written and up to date. Some of the illustrations of microscope sections of rocks are not very successful, but there are many admirable photographs of rock-structures on the large scale. The author is so keen on finding purely German equivalents for terms of classical origin that some of his terminology requires a little thought before its meaning is apparent to English readers accustomed to the older type of scientific German. The inevitable table of the average composition of the igneous rocks is here credited to V. M. Goldschmidt, instead of to F. W. Clarke's *Data of Chemistry*, and references to works in the English language are conspicuously absent.

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MONOGRAPHIE DER GATTUNG KOSMOCERAS. By ROLAND BRINKMANN. Abhandlungen der Gesellschaft der Wissenschaften zu Göttingen, Mathematisch-Physikalische Klasse, Neue Folge, Band XIII, 1929, 4, pp. vii, 123, with one plate, 2 text-figures and 28 tables.

THIS monograph is really Part V of the same author's "Statistisch-Biostratigraphische Untersuchungen an mitteljurassischen Ammoniten über Artbegriff und Stammesentwicklung", which appeared in Bd. XIII, 3, of the same publication. A shortened account was read at the International Genetics Congress in Berlin last year, and was published in *Zeitschrift für Inductive Abstammungs- und Vererbungslehre*, Suppl. Bd. i, 1928, p. 496. The whole work consists of a determined and thorough attempt to apply statistical methods to the study of all aspects of the variation and evolution of the *Kosmoceras* group, specimens of which have been collected with the most meticulous care from the successive horizons of the Oxford Clay in the neighbourhood of Peterborough. The volume actually under review is devoted to the systematics of the group, and, of course, attention is not confined to English specimens. The conclusions are to a large extent based on the statistical findings of the earlier parts of the work. As might be expected, such a basis leads to a clarity of statement which is refreshing in the literature of ammonite systematics: many of the characters of the species are expressed numerically: and tables are given in which the diagnostic characters of the species are directly contrasted. Only a prolonged study will be able to decide whether this definiteness is implicit in the actual material, or whether the author has forced an unwilling genus to lie on his Procrustean bed: but one is somewhat reassured to find that he admits the existence of intermediate forms between his species.

C. H. W.

# REPORTS AND PROCEEDINGS.

## MINERALOGICAL SOCIETY.

### 19*th March*.

Dr. A. W. Groves and Mr. A. E. Mourant: "Inclusions in the apatites of some igneous rocks."

Apatite crystals with dark cores of inclusions have been observed among the heavy minerals of some English sedimentary rocks, but there are few records of such apatites in igneous rocks. The authors record several such occurrences in granites and in volcanic rocks from Normandy, Jersey, and Brittany. Five different types are distinguished in the granite of northern Brittany alone. In one type with a definitely pleochroic core the inclusions appear to consist of biotite or chlorite, but in other types it has not been possible to determine their nature.

Mr. L. A. Narayana Iyer: "Calc-gneisses and cordierite-sillimanite-gneisses of Coimbatore, Madras Pres., and of similar occurrences in India."

The paper dealt with a suite of crystalline gneisses in the ancient Archaean complex of India of Dharwar age (Huronian), consisting of the above two facies, which are in close association. Similar suites of rock occur in different parts of India, forming a definite stratigraphic horizon. The author considers their formation as due to thermal or "infra-plutonic" metamorphism followed or accompanied by regional or dynamo-thermal metamorphism of pelitic schists and calcareous sediments.

Mr. F. A. Bannister: "A relation between the density and refractive index of silicate glasses with application to the determination of imitation gem-stones."

The study of simple glass families leads to a relation between the refractive index and density which can be applied in a modified form to the determination of imitation gem-stones. $n-N/d-D$ where $N$ and $D$ are the refractive index and density of silica glass, is plotted against $n$ by a simple graphical method, whereupon the various imitations separate into groups; the members comprising any one group are chemically similar. Doubtful cases can be solved by measuring in addition the relative dispersion.

Mr. H. E. Buckley: "The crystallization of potash-alum."

The author described the results of experiments on the differences of crystal-habit obtained under varying conditions of cooling and evaporation, and in the presence of various substances in solution.

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The proceeds of the Daniel-Pidgeon Fund for the year 1929 have been awarded by the Council of the Geological Society of London to Mr. J. Selwyn Turner, B.Sc., F.G.S., who proposes to investigate the faunal succession in the Coomhola Grits and Carboniferous Slate of County Cork.